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THE MINERAL ECONOMICS OF THE CARBONATE ROCKS



LIMESTONE AND DOLOMITE RESOURCES OF CALIFORNIA

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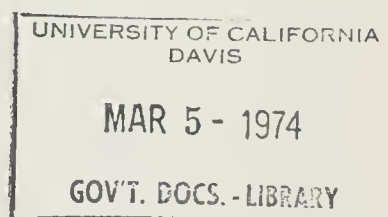
California Division of Mines and Geology
1416 Ninth Street, Sacramento 95814, 1973

LIMESTONE AND DOLOMITE RESOURCES OF CALIFORNIA

Oliver E. Bowen, Editor

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by
Oliver E. Bowen
Cliffton H. Gray, Jr.
James R. Evans



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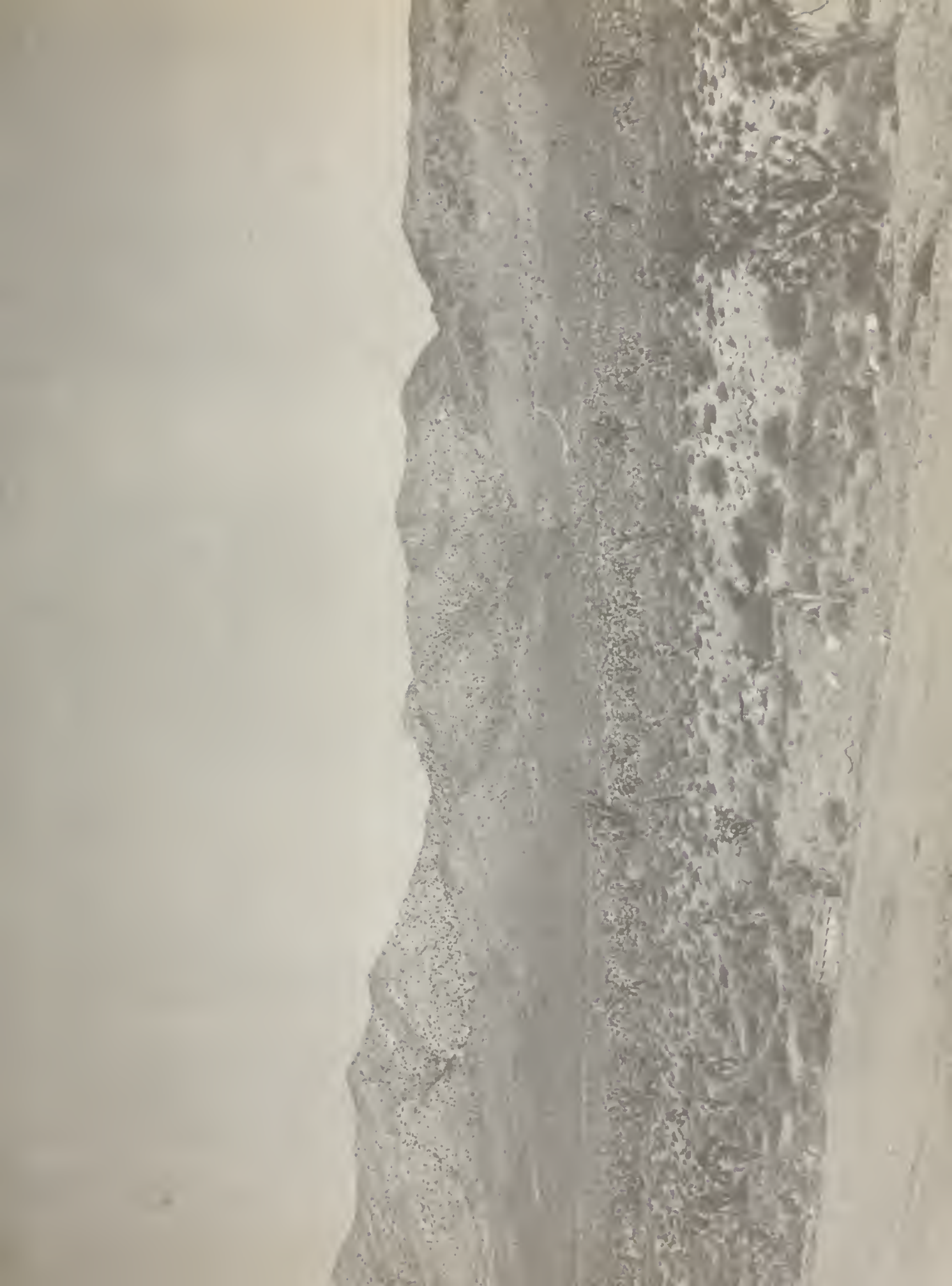
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Photo 1. Frontispiece. The south and southeast flanks of Striped Mountain in the Mescal Range of eastern San Bernardino County 12 miles north of Cima or 10 miles by road south of Mountain Pass, observer facing north. Between the highest summit in the background to the dark hill that lies behind the headframe is an unbroken section of carbonate rocks. This section begins with the well-banded dark layers of the Pennsylvanian Bird Spring Formation and passes successively through the Mississippian three-member Monte Cristo Limestone, the Devonian three-member Sultan Limestone and the Cambrian to Devonian (?) Goodsprings Dolomite. Limestone of potential economic importance is present in all of these formations except the Bird Spring.



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LIMESTONE AND DOLOMITE RESOURCES OF CALIFORNIA

Oliver E. Bowen, Editor

PLAN AND ORGANIZATION OF THE INVESTIGATION

The statewide investigation of limestone and dolomite resources of California was initiated in 1962 under the immediate guidance of Oliver E. Bowen, Senior Geologist. As conceived by his plan, the investigation, to be conducted by Division geologists, would be divided into seven parts. The first part would provide information on the mineral economics of the carbonate rocks. The other six parts would be organized on a geographic basis, as described below. Work by Division staff on this statewide investigation was conducted during numerous intervals from 1962 to 1970.

The first part, here published as Bulletin 194, contains background information applicable to all carbonate rock deposits in the state. It covers origin, mineralogy, chemistry, exploration, development, quarrying and mining, processing for market (including beneficiation) and uses and marketing of carbonate rock products.

The results of the remainder of the investigations will be made available when writing and processing are completed. These parts are arranged on a geographic basis—primarily by carbonate rock province: II, Klamath Mountains; III, Coast Ranges; IV, Sierra Nevada; V, Basin Ranges; VI, Mojave Desert; and VII, combined Transverse and Peninsular Ranges (see fig. 1). There are no deposits of any consequence in the Modoc Plateau, Cascade Range, or Central Valley provinces.

Long slender provinces such as the Coast Ranges and Sierra Nevada have been divided into northern, central, and southern regions for greater ease of dis-

central, and southern regions for greater ease of discussion. Arrangement of districts within provinces is north to south and, when more than one district begins at the same latitude, east to west. Districts are designated by various combinations of numbers—IV-A-3. Most of the discussions of the deposits will be arranged alphabetically within each district. The carbonate rock provinces and districts are listed below.

KLAMATH MOUNTAINS PROVINCE II

District II-1-A	Yreka-Etna-Callahan-Gazelle subdistrict
II-1-B	Happy Camp-Seiad Valley-Scott Bar subdistrict
II-2	Redding-Ingot-Castella
II-3	Trinity Mountains

COAST RANGES PROVINCE III

Northern Coast Ranges region (A)

District III-A-1	Humboldt
III-A-2	Mendocino
III-A-3	Clear Lake

Central Coast Ranges region (B)

District III-B-1	Healdsburg
III-B-2	North Bay
III-B-3	San Francisco Bay
III-B-4	Santa Clara
III-B-5	Santa Cruz

Southern Coast Ranges region (C)

District III-C-1	Gabilan Range
III-C-2	Panoche Hills
III-C-3	Northern Santa Lucia Range
III-C-4	Parkfield-Coalinga
III-C-5	Southern Santa Lucia Range
III-C-6	Santa Ynez

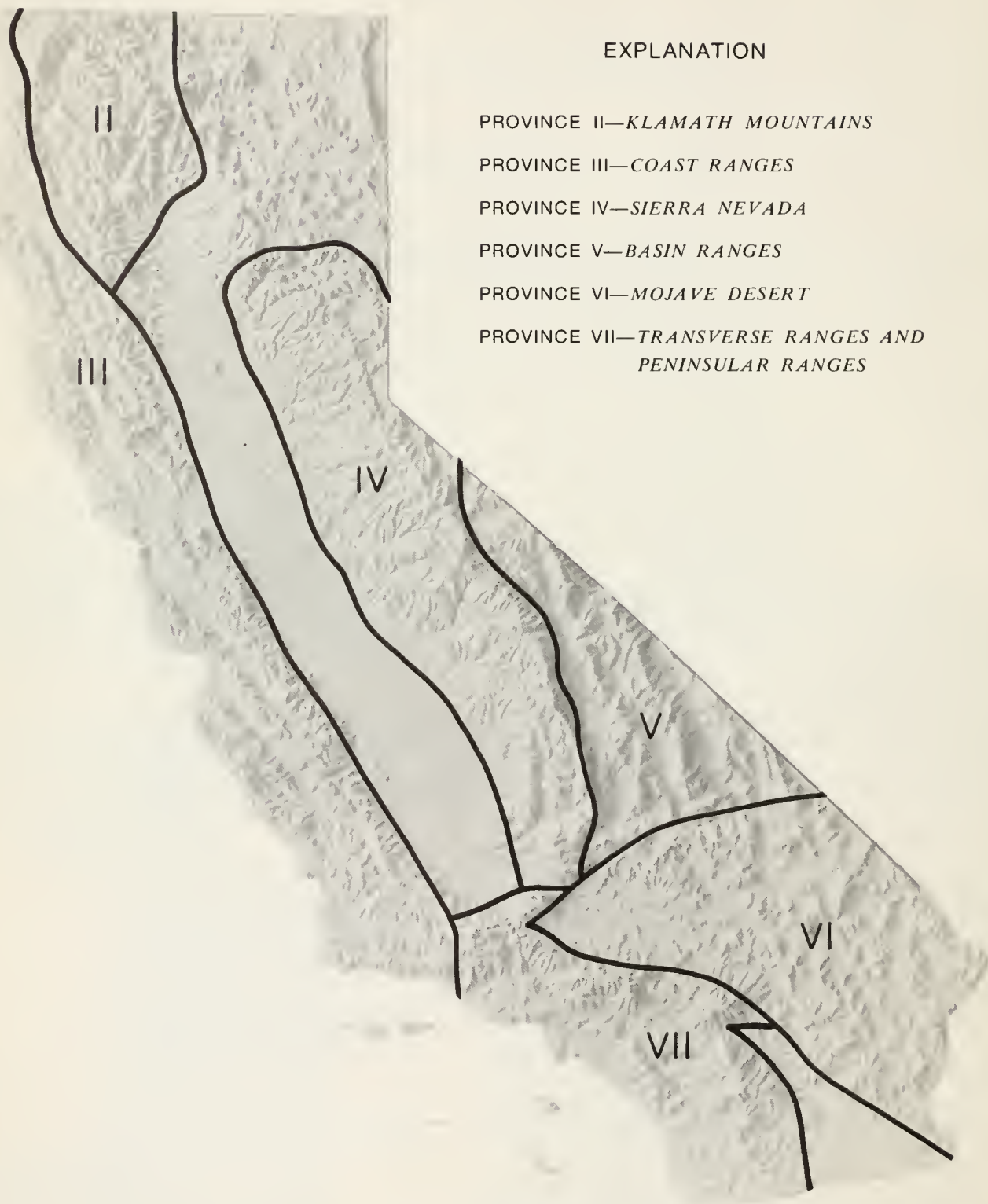


Figure 1. Index map showing carbonate rock provinces.

SIERRA NEVADA PROVINCE IV

Northern region (A)

- District IV-A-1 North central Plumas County
 IV-A-2 Southwestern Plumas-eastern Butte Counties

- IV-A-3 Sierra Buttes-Bowman Lake

Central region (B)

- District IV-B-1 Foothill belt between Auburn and Shingle Springs
 IV-B-2-A Deposits east of the Mother Lode between Placerville and San Andreas (subdistrict)
 IV-B-2-B Foothill belt west of the Mother Lode between Latrobe and Altaville (subdistrict)
 IV-B-3 Markleeville-Topaz Lake
 IV-B-4-A Belt east of the Mother Lode between Altaville and the Tuolumne River, including the Columbia-Sonora area (subdistrict)
 IV-B-4-B Foothill belt west of the Mother Lode between Altaville and the Stanislaus River (subdistrict)

- IV-B-5 West of Mono Lake

- IV-B-6 Merced River

Southern region (C)

- District IV-C-1 Lake Crowley-Bishop-Big Pine
 IV-C-2 Huntington Lake-Kings River
 IV-C-3 Mt. Pinchot-Sawmill Pass
 IV-C-4 Kaweah River
 IV-C-5 Tule River
 IV-C-6 Walker Pass-Inyokern
 IV-C-7 Kern River
 IV-C-8 Tehachapi-Caliente Creek

BASIN RANGES PROVINCE V

- District V-1 Mono Lake
 V-2 White Mountains
 V-3 Northern Inyo Mountains
 V-4 Last Chance Range and Dry Mountains
 V-5 Grapevine Mountain
 V-6 Funeral Mountains
 V-7 Cottonwood Mountains and Northern Panamint Range
 V-8 Southern Panamint Range
 V-9 Lee Flat-Darwin
 V-10 Nopah and Resting Springs Ranges
 V-11 Black Mountain
 V-12 Argus and Slate Ranges

MOJAVE DESERT PROVINCE VI

- District VI-1 Mesquite Mountains-Clark Mountain Range-Mescal Range-Ivanpah Mountains

- VI-2-A Silurian Hills subdistrict
 VI-2-B Avawatz Mountains subdistrict
 VI-2-C Soda and Cave Mountains subdistrict
 VI-3 New York Mountains and Providence Mountains
 VI-4 Kelso-Old Dad Mountain-Devil's Playground
 VI-5 Alvord Mountains-Lane Mountains-Calico Mountains
 VI-6 Hinkley
 VI-7 Piute, Old Woman and Ship Mountains-Kilbeck Hills
 VI-8 Marble and Bristol Mountains
 VI-9 Victorville-Oro Grande
 VI-10 Shadow Mountains-Adelanto
 VI-11 Riverside-Big Maria-Little Maria-Palen and Arica Mountains
 VI-12 Eagle Mountains
 VI-13 Blythe-Palo Verde
 VI-14 Chocolate Mountains

TRANSVERSE RANGES AND PENINSULAR RANGES PROVINCE VII

- District VII-1 Tehachapi Mountains and Pleito Hills
 VII-2 San Gabriel Mountains
 VII-3 San Bernardino Mountains
 VII-4 Santa Susana and Santa Monica Mountains
 VII-5 Colton-Riverside (Jurupa Mountains)
 VII-6 San Jacinto Mountains and northern Santa Rosa Mountains
 VII-7 Santa Ana Mountains, San Joaquin Hills and Palos Verdes Hills
 VII-8 San Ysidro Mountain-Coyote Mountain-Southern Santa Rosa Mountains
 VII-9 Coyote, Fish Creek, Jacumba and Laguna Mountains
 VII-10 San Diego Mountains

Plate 1 (scale 1:1,000,000), accompanying this bulletin, shows the location of all known carbonate rock deposits in California. On it are delineated all province, sub-province, district, and county boundaries plus the land net, main highway network, and the railroad routes. Plate 2 (scale 1:2,000,000) shows the approximate location of the principal limestone- and dolomite-consuming plants and the larger processing plants in California as of 1970.

This bulletin also contains a complete index to the limestone and dolomite deposits of the state. This index includes all names presently in use, as well as names (synonyms) known to have been used formerly. A list of processing plants also is included.

ABSTRACT

California's vast resources of carbonate rocks and seashells supply 14,000,000 tons of calcareous materials to the cement industry each year. An additional 4,500,000 tons are consumed by manufacturers of stone aggregates, lime, steel, roofing granules, sugar and glass. The value of carbonate rocks to the state's economy is enormous.

Limestone, dolomite and seashells are the three principal sources of calcareous and magnesian materials in California. All of these are found in marine sediments or their metamorphosed equivalents, except for a very minor proportion formed from evaporation of mineral-laden spring water. A preponderance of calcareous sediment is formed by aquatic organisms—both plant and animal. Biochemical and chemical precipitation also contribute to calcareous accumulations in marine sediments as well as to sea-floor chemical replacement. Compaction and lithification of carbonate sediment is a complex process that involves widespread redissolving, reprecipitation, cementation, and dehydration.

The predominant mineral of limestone is calcite (CaCO_3), whereas the principal mineral of rock dolomite is the mineral dolomite ($\text{CaMg}(\text{CO}_3)_2$). Inasmuch as high-calcium carbonate rocks cannot, in most cases, be used for the same purposes as magnesium-rich carbonate rocks, the proportions of calcite and dolomite present are very important. The various means of distinguishing between calcite and dolomite are dependent upon the fact that calcite is more readily soluble or reactive with water, acids and most chemicals and dyes than dolomite. Dilute acids and dyes are most commonly used, both in field and laboratory, as identifying aids.

Common deleterious impurities found in limestone and dolomite are silica, clay and organic matter. A host of minerals may be introduced into carbonate rocks by emanations and solutions from invading molten rocks, such as complex silicates, sulfides and sulfo-salts.

The carbonate rocks are classified on the basis of the amounts of lime, magnesia and silica present. In industrial practice, "high calcium" limestone is synonymous with "chemical grade" limestone and signifies a rock containing 95 percent or more of CaCO_3 . Dolomite, which has a very restricted use in California, must contain about 20 percent MgO to be marketable as a chemical or refractory raw material.

Lime, magnesian lime, and carbon dioxide are all widely used industrial chemicals derived by calcination of limestone and dolomite. Temperatures at which these compounds dissociate range from 545°C (for dolomite) to 1500°C (for calcite). The metallic oxides combine readily with water to form hydrates that have uses different from the corresponding oxides. Suitability of carbonate rocks as sources of lime or CO_2 vary considerably depending upon texture, structure and other characteristics as well as upon the chemical content.

Carbonate-rock deposits may be acquired by purchase or lease from private owners or in some cases by mineral location under the mining laws of the United States; a few, such as oyster shell deposits, lie on tidelands administered by the State and must be leased from the State Lands Commission.

California has few flat or nearly flat-lying carbonate formations; most California carbonate-rock bodies are thick, rather structureless masses of variable chemistry. Igneous intrusions and interbeds of rock of non-carbonate character often necessitate selectivity during quarrying. Land-surface relief is commonly considerable and often extreme. Consequently, one cannot mine a few select beds of surface-exposed rock over large acreages. Five deposits of industrial limestone or dolomite currently are mined underground, and one major portland cement plant is supplied wholly by underground mining. However, bench-

quarrying from bench spacings of 25 to 50 feet is most commonly used.

Carbonate rocks are transported by truck, rail, belt-conveyor, pipeline (as slurry) and water-borne means, the latter method being cheapest. Specially designed equipment is constantly being devised to lower transportation costs and facilitate loading and unloading. The trend is toward larger-capacity rigs. Portable crushing and sizing units are in common use. Use of large barges and ships with automatic loading and unloading devices is increasing.

Processing carbonate rocks, for many purposes, simply involves crushing and sizing. Where trace impurities are critical, a washing and scrubbing circuit may be added. When the product desired must be finely ground, more elaborate equipment and much greater outlay of capital are necessary. As the result of rising transportation, deposit acquisition and other costs, upgrading of the marginal and low-grade parts of carbonate rock deposits is becoming more and more prevalent. Beneficiation methods include froth flotation, heavy media separation, electronic color and reflectance sorting and various new radiation-sorting techniques.

Limestone is one of a select few raw materials that are absolutely necessary to the existence of modern industry and our present civilization. The carbonate rocks are low-priced raw materials and most products made from them are low-priced. Consequently, they must be produced as near as possible to marketing centers or the manufacturing plant that consumes them. Most active carbonate rock deposits lie within 150 miles of the principal consuming centers and a majority are within 75 miles. Rail freight costs 2 to 3 cents per ton mile, belt conveyor freight about the same; truck freight is 3½ to 7 cents per ton mile. Water freight, on the other hand, can be handled for as low as 1 or 2 mills per ton mile. Import duties are on the order of 25 cents per ton.

Costs of quarrying carbonate rocks and getting them into the processing plant range from 40 to 80 cents per ton in very large volume operations, such as cement plants, to several dollars per ton in small operations. Prices obtained on the open market for limestone and dolomite in large and medium-sized pieces range from a dollar or slightly less per ton, for some aggregate and construction stone, to as much as \$6.25 for rock very low in iron suitable for glass manufacturing. Limestone having a CaCO_3 content of 96 to 98 percent and sized to dimensions such as 2 x 4 inches or 4 x 6 inches sells for \$3 to \$6.25 per ton. Ground products bring from \$9 to \$25 per ton depending upon specifications, volume of sales, and related factors. Packaging commonly costs three or four dollars per ton.

The history of utilization of carbonate rocks in California dates from the building of the Spanish missions in the 1700's. Disastrous fires among frame buildings in the middle 1800's resulted in great demand for lime for masonry construction. Use of carbonate rocks was also greatly heightened by the advent of the portland cement industry in 1895-1905. The multiple use of carbonate raw materials in our modern technology has developed principally during the past fifty years.

Development and utilization of hitherto unused deposits of California limestone and dolomite on a major scale will depend primarily upon: (1) patterns of population growth; (2) advances in manufacturing technology; (3) construction of important arteries of transportation; (4) placement of trunk utility lines; and (5) degrees of restriction placed upon new and existing quarries and manufacturing plants through urban development. Areas particularly notable for near-future development include the Coyote and Fish Creek Mountains of Imperial County; Back Canyon in the Tehachapi district of Kern County; the north slopes of the central San Bernardino Mountains; the Marble Mountains and Cima area of eastern San Bernardino County; the Keeler area east of Owens Valley in Inyo County; the Lake Hemet vicinity and Maria Mountains of River-

side County; the Frazier Park area of Ventura County; the San Marcos Pass vicinity of Santa Barbara County; Pico Blanco in Monterey County; the Murphys-Columbia-Sonora area of the central Sierra Nevada; the Volcano vicinity in Amador County; and the Lake Shasta area of Shasta County.

THE MINERAL ECONOMICS OF THE CARBONATE ROCKS *

by OLIVER E. BOWEN,** CLIFFTON H. GRAY, Jr. †, AND JAMES R. EVANS ‡

INTRODUCTION

California, with the largest population of any state in the Union and among the fastest-growing, is fortunate to have vast resources of carbonate rocks to supply its rapidly expanding industries. The California cement industry alone, the largest of any state in the United States and probably of any equivalent political unit in the world, consumes about 14,000,000 tons of limestone and other calcareous materials each year. More than 4,500,000 additional tons of carbonate rocks are consumed annually by a great number of other industries, among which the principal users are: aggregate manufacturers serving the construction industry, lime manufacturers, steel mills, manufacturers of roofing granules, sugar refineries, and glass manufacturers, in that approximate order. The value of carbonate rocks to the state's economy is enormous.

Although California is well-endowed with carbonate rocks suitable for virtually all industrial needs, not all of these are well-placed in relation to the principal markets. As most carbonate rock commodities are low-priced, proximity to markets is of prime importance to keep transportation costs low. For example, tidewater deposits are few in California, as well as in Oregon and Washington; as a result, low-cost waterfreight imports into some areas of these states are competitive with in-state sources. Because of remoteness, lack of water, or poor living conditions for operators at some southern California deposits, some classes of carbonate rock for southern California markets still are being imported from Nevada. Improved transportation and freight handling or adjustment in current rail freight rates could change this condition.

California's burgeoning population, with its resultant expanding manufacturing and construction industries, offers business opportunities unmatched elsewhere. Requests to the Division for information on the entire carbonate rock picture in California have been unprecedented in number and are constantly increasing. For this reason, the authors have attempted to gather together in this bulletin, as concisely as possible, under one cover, all available information pertinent to the origin, type of occurrence, location, acquisition, economic evaluation, mining and processing and marketing of the carbonate rocks in California and to list available sources of additional information. The reports containing the results of the other parts of the investigation will describe the known deposits of carbonate rocks in California, region by region in separate covers, in all available geologic and engineering detail, with illustrations and maps.

Many friends of the California Division of Mines and Geology have cooperated in gathering or supplying data for this investigation. The authors are par-

ticularly indebted to Fred N. Woods III of California Rock and Gravel Company, Donald Gustafson of Premier Resources, Inc. and Woodrow Slade of Owens-Illinois Glass Company for much cost, freight rate, and marketing information. We are also deeply indebted to all of the portland cement producers of California for much information and for many courtesies extended by all of their operations personnel. Especially helpful were John Wolfe, Al Lang and Len Caetano of Ideal Cement Company; Bert Wilson, Jack Woodward, Felix McGinnis, J. B. Alexander, and Morris Gudal of Southwestern Portland Cement Company; Randall Wightman, John Sauer, Peter Nalle, and Bert Wilkinson of the Riverside Division of the American Cement Corporation; Wilson Hanna, Ian Smith, and Jack Joyce of California Portland Cement Company; Tom Mullan, Donald Towse, and Angelo Covelo of Kaiser Cement and Gypsum Corporation; Robert Kinzie and Norman Jones of Pacific Cement and Aggregates Division, Lone Star Cement Corporation; Lloyd Rentsch and Allen Johnson of Monolith Portland Cement Company; T. C. Slater, Bill Fuller, Orin Weeks, and Jim Curry of Calaveras Cement Division and Bill McCandlish of U. S. Lime Products Division of The Flintkote Company; Walter Stinson of El Dorado Limestone Company; Robert Lawson of Diamond Springs Lime Company; Fred Johnson of Pacific Limestone Products Company; Jim Nissen of Porterville Limestone Company; Elmer Piercy and Bill Crumpler of Chas. Pfizer & Company; Jim Wiseman and Henry Helmers of Westend Chemical Division of Stauffer Chemical Company; and Ira Bechtold, consultant—who all aided materially in providing data for this volume. Howard Harris was very helpful to us in locating numerous deposits in the northern Gabilan Range and in gaining access to properties. Olaf Jenkins and Bruce Woolpert of Granite Rock Company provided planes for air reconnaissance and helped the authors in many other ways. Gene deZan kindly provided helicopter support for examination of deposits in the Blythe area of Riverside County.

William H. Crutchfield, Jr., of the Atchison, Topeka & Santa Fe Railway mining department, as well as numerous individuals from the freight rate departments of the Santa Fe and Southern Pacific Railroads, kindly provided most of the information upon which the freight rate tables are based.

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SIGNIFICANCE AND INTERPRETATION of CHEMICAL ANALYTICAL DATA

The carbonate-rock analyses included in the subsequent reports of the statewide investigation have been made and gathered together over a period of several decades by many organizations, including government agencies, commercial testing laboratories and industries. The sampling methods in the field and analytical methods employed have varied, and so has the completeness of the analyses. For these reasons it has been difficult to use a single reporting method and to comment meaningfully on the results.

The samples were selected in the field, as carefully as possible, expressly for chemical analysis so as to best reflect the characteristics of the deposit or formation sampled. Hence the samples and their corresponding analyses are believed to be fairly reliable representations of the deposit or formation under discussion. However, it is seldom possible to collect and analyze as many samples as would be statistically desirable; some samples were smaller than optimum because they were collected in places far away from large deposits where both access and transport of samples were difficult. Therefore, for many of the deposits, the few surface samples obtained are useful only as guidelines for further exploration sampling and analytical work by prospective operators. Wherever possible the various authors have commented on the mineral composition and analytical data to try to make them more understandable both to readers without detailed knowledge of the economics of the carbonate rocks and to those connected with industries which use the carbonate rocks as raw materials.

Component Composition of Carbonate Rocks

Carbonate rocks consist most commonly of three components: carbonate minerals, silicate minerals (including silica in the form of quartz, chalcedony or opal) and organic material. For most industrial uses the only desirable component is calcite, calcium carbonate (CaCO_3), whereas the other major carbonate, dolomite, $\text{CaMg}(\text{CO}_3)_2$, is harmful if present in amounts greater than a few percent. In a few special industries a high MgCO_3 content is necessary.

The carbonate minerals are soluble in most acids. The silicates are insoluble in most acids, except hydrofluoric. For most industrial uses, except portland cement, the silicate minerals are harmful or at best are diluting impurities in the rock. In judging the economic potential of a limestone, it is well to remember that magnesium may be present in either the carbonate or the silicate component, or in both. The alkalies, sodium and potassium, when present, are confined almost entirely to the silicate component.

The organic component is usually small and harmless, except in manufacture of glass and for some chemical uses, and disappears in the heating process. When carbonate rocks are undergoing metamorphism the volatile organic components gradually disappear and the residue is graphite (carbon). The gaseous effluent of the carbonate component, the organic component and the combined and absorbed water

together form the volatile part of the rock, which disappears on heating. This is termed "ignition loss," discussed later.

Digestion of the Sample

Before analysis can be undertaken, it is necessary to disintegrate the carbonate rock and get it into solution. All digestion methods destroy the carbonate minerals, whereas the silicate minerals (or component) may be slightly, partly, or fully, destroyed, depending upon the method and the acid used. Hydrochloric or nitric acid digestion attacks silicates only slightly. Therefore, in this type of digestion, it is not possible to say accurately whether the insoluble minerals consist of silicon dioxide alone (usually termed silica or SiO_2) or other silicate minerals, which may contain harmful elements. The most complete digestion is possible if the rock powder is first heated for ten minutes or so at $2,000^\circ\text{F}$. The carbonate component in the powder, while losing its carbon dioxide, attacks the silicate minerals, rendering them more easily digested in the acid. This kind of attack affects various silicates differently, and one cannot guarantee that critical elements such as magnesium and the alkalies have gone entirely into solution.

A complete digestion can be made only by fluxing the rock powder with sodium carbonate or by use of hydrofluoric acid. The sodium carbonate method renders all elements ready for determination except sodium. Use of hydrofluoric acid volatilizes the silica, which then cannot be determined from this solution. The only way to obtain an accurate total analysis is to employ these or similar double attacks on two different portions of the sample. As it is commonly not possible to say what method has been used during the many analyses quoted in this bulletin and in later reports on this series of investigations, the reader must make his own judgment as to the significance of the reported analytical figures.

Carbonate rock analyses usually list the oxide components in the following manner and order:

SiO_2 or Insoluble	
Al_2O_3	} Collectively called R_2O_3
Fe_2O_3	
MgO	
CaO	
Na_2O	} Collectively called alkalies
K_2O	
P_2O_5	
CO_2 or Ignition loss	

SiO_2 or Insoluble

If the analysis reports " SiO_2 " it may mean SiO_2 only, or SiO_2 plus various amounts of unattacked silicates, as outlined in the preceding paragraph on digestion. If the silica content amounts to more than 5 percent but the rock otherwise is suitable as to its magnesium content, it is advisable to consider critically the possible magnesium content of the unattacked silicates. If the analysis reports an "insoluble" component, it is clear that this means SiO_2 plus the bulk of undigested silicate minerals. The usefulness of the analysis should again be weighed against the composition of the carbonate part in relation to the amount and probable character of the undigested, i.e. insoluble, material.

This same principle of judging the significance of the SiO_2 or insoluble component is also valid for the metallic oxides discussed below. This means that, if one or several of the elements are approaching the critical point for a specific use, it is always best to ask: "Would additional amounts possibly present in the insoluble silicates exceed the tolerable limit?"

Al_2O_3 and Fe_2O_3 ("R₂O₃")

In most carbonate rocks, the Al_2O_3 content amounts to about 20 percent of the silica content, giving a rough test of the accuracy of the analysis. Alumina is seldom critical unless present in large amounts and is commonly useful in the cement industry. Fe_2O_3 or total iron is a harmful component in the glass, filler, and some chemical industries. For some of these uses, the iron content must not exceed a few hundredths of a percent or, at most, one- or two-tenths of a percent. In these low concentrations, most analytical methods are relatively less accurate than in higher concentrations; and, for these purposes, the iron content should be carefully rechecked.

"R₂O₃" most commonly signifies the total amount of the two oxides present plus titanium, phosphorous, and part of the manganese. Usually these three latter elements occur only as insignificant traces in carbonate rocks. "R₂O₃" does not tell anything at all of the relative amounts of aluminum and iron present.

MgO and CaO

In carbonate rock analyses, the emphasis is on these two elements. The amount of CaO in usable limestones ranges from 40 percent in impure limestone to 56 percent in pure limestone. In these high concentrations, it is irrelevant to know for preliminary purposes the CaO content more accurately than from 1.0 to 0.5 percent, an accuracy that is generally achieved. Most dolomites have an MgO content in the range of 15–21 percent, which is acceptable for some purposes. For such samples, again, the accuracy of ± 1 percent generally achieved is satisfactory.

For many industrial purposes, however, a very low content of MgO is mandatory. Therefore, an MgO content of 5 percent or less should be looked at critically, and the questions asked should include: "How representative is the sample? How accurate is the analysis? Is the MgO total content indicated or only that portion derived from the soluble carbonates?"

Na_2O and K_2O (alkalies)

These generally are found in the silicate impurities in carbonate rocks—mainly in micas and feldspars. They are seldom analyzed except by cement companies. If the SiO_2 and Al_2O_3 or R_2O_3 are high (5–10 percent), it is of value to know the alkali content of the rock, especially if cement manufacturing is planned.

P_2O_5

The phosphorus pentoxide content in carbonate rocks is usually low—on the order of a few hundredths of one percent. The amount is critical if the stone is to be used in fluxing of metals. Although current methods of analyzing the P_2O_5 content on these low levels are accurate, it may be advisable to check the older analyses, especially if the P_2O_5 content reported is high

CO_2 and Ignition Loss

The bulk of combined CaO and MgO in carbonate rocks is present in the form of carbonates. Therefore, the CO_2 content should approximately match the amount necessary to combine with the reported MgO and CaO content, but this may not be exactly so for several possible reasons. If the MgO and CaO are partly in silicates, the CO_2 content will be lower than required to satisfy the MgO and CaO content for pure carbonate composition. If the CO_2 content exceeds the amounts required to satisfy the MgO and CaO contents for pure carbonate composition, it is likely that part of the CO_2 originates from organic material.

For routine and preliminary analyses, ignition loss is usually determined. This term includes CO_2 , H_2O , and other volatile components given off from organic, sulfurous, and phosphatic materials. In carbonate rocks, ignition loss is only a few percent greater than the true CO_2 content and hence is commonly a good gross check on the correctness of the CaO and MgO content, as well as being close to the true CO_2 content.

Instrumental Analyses

The 900-odd carbonate sample analyses made by the Division of Mines and Geology laboratory during 1963–67 for the limestone and dolomite resources project are the result of combined x-ray fluorescence and wet chemical analysis methods. This procedure today is commonly used in industries based on carbonate raw materials. Although x-ray fluorescence is superior in reproducibility, its accuracy is not comparable with wet chemical analysis. Therefore, it is necessary to make special comment on these results.

X-ray fluorescence was used to analyze for SiO_2 , Al_2O_3 , Fe_2O_3 , CaO, and occasionally K_2O , MnO, and TiO_2 . Wet chemistry was used to analyze for MgO and P_2O_5 . Ignition loss was determined instead of CO_2 , for expediency. The emphasis of the method has been to make an accurate MgO determination.

A statistical analysis has been made to determine the accuracy of x-ray fluorescence procedure. Results as tabulated below are applicable to 95 percent of the analyses:

Oxide	Range, Weight %	Deviation (%) from Weight % = C %	Example: C % \times Weight % = \pm Limits	If:	Then true value is between
SiO_2	1–10	10	SiO_2 5%		4.4–05.5%
Al_2O_3	0.5–02.0	15	Al_2O_3 1%		0.85–01.15%
Fe_2O_3	0.2–01.0	10	Fe_2O_3 0.5%		0.45–00.55%
CaO	30–55	2.5	CaO 40%		39–41%

In practical application, this means that, if a specification for a limestone permits no more than 0.20 percent Fe_2O_3 , a rock reported to contain 0.22 percent still might fall within the acceptable range if the possible analytical error were corrected. Therefore, an additional program of sampling and analysis might be warranted.

For MgO, the relative deviation is 3 percent. Again an example: If the maximum allowable MgO content is specified to be 3 percent, a rock reported to have an MgO content of 3.1 percent may be well within the critical limit.

Analysis Reporting

By tradition, the oxides are reported to the second decimal. It is clear from the preceding paragraph that the second decimal is very seldom correct and then only by chance. Nevertheless, the old reporting system prevails among some analysts, whereas modern practice is to report only to include the first possibly incorrect digit; rather than report CaO to be 40.18 percent, with ± 2.5 percent possible deviation, an equally correct and more reasonable figure is 40 percent. Further, if Fe_2O_3 is reported to be 0.33 percent (possible deviation 10 percent), the analysis is more properly reported at 0.3 percent. As the analyses gathered together in this investigation are from many sources, we have not attempted to standardize the reporting procedure.

Another tradition in reporting chemical analyses is to add up their components and to try to achieve a figure of 100 percent. This is, however, not necessarily a measure of the good quality of the analysis, as is evident in previous comments. First of all, the CO_2 or ignition loss many times has been determined by difference; that is, by deducting the sum of the other components from 100. In these cases, the sum consequently must be 100. On the other hand, analyses can easily be several percent under 100 percent and still be good, inasmuch as deviations from the true value can all be in the same direction. Furthermore, the rock probably has not been analyzed for all elements—only the critical ones. Therefore, it is best to calculate the probable mineral composition of the rock and then check to see how the individual oxide components match the probable mineral content.

CHAPTER 1

THE ORIGIN, CHEMICAL AND MINERAL CONTENT AND DISTINGUISHING CHARACTERISTICS OF LIMESTONE AND DOLOMITE

By Oliver E. Bowen and James R. Evans

General Statement

Under present economic conditions in California, limestone and dolomite are the only carbonate rocks that are present in quantities large enough and pure enough to be of economic interest. Estuarine accumulations of seashells also occur in deposits large enough to be of economic interest. Magnesite-bearing vein deposits, once the principal source of magnesium compounds in California, are so small and so difficult to mine cheaply that under present technology dolomite and sea water have completely taken the place of magnesite as raw materials. Consequently, rocks formed of magnesite, siderite, ankerite and the other less common carbonate minerals need be mentioned only in passing. The calcite and dolomite-rich rocks are by far the most important and are the only ones thoroughly discussed in this bulletin.

Origin and Accumulation

An overwhelming majority of limestone and dolomite deposits are sedimentary rocks (or their metamorphosed equivalents) formed in bodies of water by direct organic secretion, biochemical precipitation, chemical precipitation, accumulations of detrital sand-sized grains or a combination of these processes. A few are formed by hydrothermal deposition in fissures and cavities from carbonate-laden mineral springs. Still fewer originate by evaporation of carbonate-bearing surface or near-surface water. Most California limestones accumulated in ancient seas and most dolomites have been derived by chemical replacement of limestones, in a majority of cases by seafloor replacement but also, rather commonly, by replacement that has taken place during the orogenic or fold-mountain building episodes of earth history.

Many aquatic organisms, both plant and animal, secrete calcium carbonate for protective and supporting parts. As many of these organisms are both prolific and colonial, or at least gregarious in habit, their limy remains may accumulate and be preserved in large concentrations. The coral and algal reef complexes in tropical and semitropical parts of the world are the most striking examples wherein masses several hundreds of feet thick and many thousands of square feet in area simply accrue in situ by direct action of large numbers of small growing organisms. Remains of free-floating and bottom-dwelling micro-organisms may also contribute materially to the bulk of an ac-

cumulating mass of carbonate material. Micro-organisms may also contribute indirectly to the chemical precipitation of carbonate minerals by upsetting the equilibrium of the aqueous system in which they live. Changes in temperature and the intermixing of waters of different mineral concentrations and temperatures may also result in precipitation of carbonate minerals without the aid of organisms. Evaporation of sea water in shallow marginal marine basins favors precipitation of various dissolved minerals, including the carbonates. The common occurrence of limestone bodies associated with and often enclosed entirely by volcanic rocks strongly suggests that introduction of mineral-laden waters of volcanic origin into seas and lakes may have profoundly influenced the formation of some limestone and dolomite deposits, as well as some accumulations of iron and manganese-bearing carbonate minerals.

There is considerable evidence that great volumes of California carbonate rocks were laid down as detrital sediment, i.e. sand or silt-sized particles eroded from adjacent reef and shell-accumulation sources and re-concentrated and re-laid by moving water. Unfortunately, subsequent metamorphism and dolomitization have obliterated much of the evidence. Consequently, the precise relative importance of purely chemical processes as compared to the action or influence of organisms in the formation and accumulation of carbonate rocks has not been well established.

Some marine carbonate deposits grow in part by accretion of tiny, interbonded calcite crystals as well as by settling of precipitated, more or less amorphous carbonate ooze. However, the greatest bulk of most marine-laid limestones probably originates as current-concentrated sand and silt-sized particles eroded from reef, seashell or oolite accumulations plus precipitated ooze. Under microscope examination, numerous limestones can be seen to have formed by dehydration of colloidal carbonate gels without much crystallization. However, colloidally derived material probably does not form the major part of most limestone deposits.

Dolomite may originate as a chemical or biochemical precipitate or accretion product in much the same fashion as limestone. Such accumulations, however, are uncommon, generally thin, and of limited areal distribution. More commonly dolomite forms by chemical replacement of limestone (calcite) on the sea

floor not very long after deposition. Replacement of this type follows no set pattern and may be partial or complete, i.e. a given bed may either have replacement patches of dolomite dispersed through an otherwise calcitic limestone, or the entire bed may be replaced by dolomite. Dolomitization, the process of forming dolomite by chemical replacement of some pre-existing material, is a process that also accompanies hydrothermal alteration and metallic ore-mineral introduction. It may be an active and rapid process at elevated temperatures, particularly when associated with near-surface volcanism or emplacement of granitic intrusions at depth, or it may be slower and more passively associated with continuing sea-floor deposition at relatively low temperatures. Dolomite formed during the emplacement of molten rocks in mountain-building episodes commonly is fracture- and fault-controlled and may form a recognizable, cross-cutting pattern superimposed on other dolomite bodies formed by sea-floor replacement. Because conversion of limestone to dolomite theoretically involves a loss in volume of about 13 percent, dolomitization of a limestone body may cause it to increase in porosity.

Compaction and lithification of unconsolidated carbonate sediment is a complex process that involves widespread redissolving, reprecipitating, cementation, dehydration and authigenic crystallization. Burial and loading or piling on by later-deposited sediment causes the carbonate particles to go readily into solution at those grain-contact points under greatest pressure and to be redeposited in voids or at points where the load stress is lowest. Through this and allied processes a porous coral-reef limestone, an accumulation of seashells or shell fragments, a limestone rendered porous by dolomitization or a carbonate-rich sandstone containing abundant pore spaces and having a high degree of permeability all tend to lose both porosity and permeability with time. Although Murray (1960, p. 66-67) states that porosity through dolomitization may reach as much as 30 percent, Pirson (1958, p. 13-17) states that development of porosity in limestone and dolomites which form oil field reservoirs is mainly through mechanical fissuring and chemical leaching. Primary porosity in limestones seldom gives economical reservoirs." Most California carbonate rocks have low porosity and consist of dense masses of interlocking crystals. This may be due in large part to the intense folding and metamorphism by heat and pressure that most California deposits have undergone.

The conspicuous calcareous tufa deposits seen along the present and ancient shorelines of desiccating saline lakes in California and Nevada (i.e. Searles Lake, California, and Pyramid Lake, Nevada) form predominantly by action of lime-secreting algae. Introduction of warm, calcareous spring water into such an environment enhances the process. Algal tufa deposits grow in somewhat the same fashion as coral reefs, but the resulting deposit is relatively structureless in comparison to the normally well preserved colonial corals and algae of marine reefs. Calcareous tufa deposits seldom are sufficiently extensive to be of economic importance although modest tonnages are sold as ornamental stone in California.

A few deposits of sufficient size and purity to be of potential economic importance have formed by evapo-

ration of carbonate-laden spring water. Known as travertine or onyx (when banded), such rock grows by accretion around multiple spring vents, and in some cases deposits aggregating many millions of tons result. Algae, bacteria and other organisms commonly aid the accumulation process. Several limestone deposits near Shoo-fly, Plumas County, and the deposits that once supplied cement plants at Cowell, Contra Costa County, and Cement, Solano County, are of this type.

Calcareous caliche deposits, some sufficiently extensive to be used as supplemental sources in cement manufacturing, form in desert climates as the result of evaporation of carbonate-laden, near-surface groundwater. These evaporites or caliches, as they commonly are called, generally are mixed with more or less alluvial detritus. Caliche was the principal raw material used in the early-day Jamul Ranch cement plant in San Diego county and is used in small amounts at several desert cement plants today.

Composition and Properties

The mineral content of the common carbonate rocks is simple except where clay, sand, volcanic ejecta or other detritus intermingled with the calcareous materials during sedimentation or where emanations from igneous intrusions have introduced new materials by replacement. The predominant mineral of limestone is calcite (CaCO_3), whereas the principal mineral of rock dolomite is the mineral dolomite ($\text{CaCO}_3\cdot\text{MgCO}_3$). Aragonite (also CaCO_3 but different in crystal form) is the mineral commonly secreted by most organisms and is abundant in newly accumulated shell limestones. With time, however, it changes to calcite and is not an important constituent of most limestones. Inasmuch as magnesium-rich carbonate rocks cannot, in many cases, be used for the same purposes as high-calcium carbonate rocks, the proportions of calcite and dolomite present are very important. Consequently, numerous methods have been devised for distinguishing between the minerals calcite and dolomite and even between aragonite, calcite and dolomite.

The means of distinction most easily used in both field and laboratory depends upon the fact that calcite is more readily soluble or reactive with water, acids and certain other chemicals than is dolomite. Calcite effervesces freely and vigorously at common atmospheric temperatures in cold, dilute (3 or 4 parts water to 1 part chemically pure acid) hydrochloric acid, whereas dolomite reacts very feebly or not at all. Calcite is considerably more soluble in rain water than dolomite, and the weathered surfaces of rocks made up of calcite and dolomite usually differ considerably in appearance (see photos 2 and 3). When patches of the two minerals occur together in the same rock exposure, the dolomite almost invariably stands out above the calcite because it weathers less readily through the dissolving action of water. Furthermore, the surface of most calcite-rich limestones is covered with sharp-edged, cup-shaped solution pits, but rock dolomite lacks these and is apt to be crisscrossed by shallow, depressed seams, like the surface of an elephant's skin (see photos 4, 5, 6 and 7). In many California deposits where dolomite and limestone are intermingled, the replacing dolomite is higher in iron than the lime-



Photo 2. The uneven, deeply crevassed surface of weathered dolomite marble of the Paleozoic Calaveras Formation near Columbia, Tuolumne County, exposed on a surface laid bare by placer mining for gold. Similar rock nearby is quarried for use as white terrazzo chips and ornamental stone. Placers in the vicinity yielded about \$87,000,000 in gold.

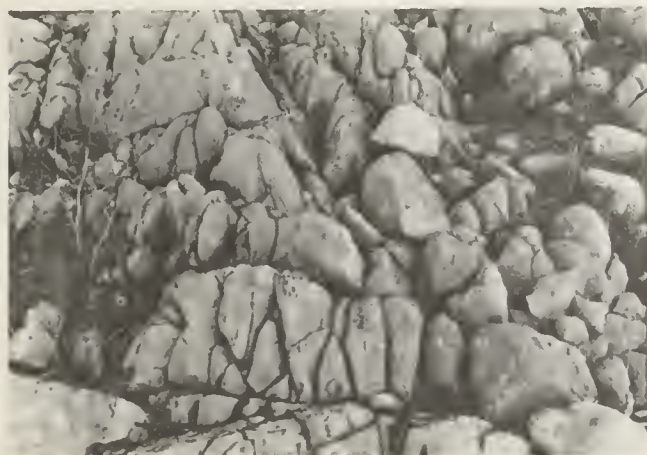


Photo 3. A deeply crevassed outcrop of coarsely crystalline, high-calcium limestone of the Paleozoic(?) Sur Series, on the south slope of Fremont Peak, Gabilan Range, Monterey County.

stone, and commonly weathers pale-buff or even a noticeable brown in contrast to the usually white to pale blue-gray limestone with which it is associated. Many California dolomites and dolomitic limestones also tend to have a higher silica content than the adjacent limestone, and the silica further reduces the susceptibility to weathering and enhances slightly the development of pronounced relief of weathered surfaces.

Unfortunately, most of the readily apparent differences in surface textures between limestone and dolomite do not apply on freshly broken surfaces, so that they are of little value to the quarryman in quality control problems. The most suitable methods for distinguishing the proportions of calcite and dolomite in freshly quarried samples or in drill cores are chemical analysis or staining. (The reader is referred to the special list of references on staining methods at the end of this chapter.)

Various chemicals stain calcite but do not affect dolomite under properly controlled conditions. Staining tests have also been used to distinguish between



Photo 4. Typical, sharp-rimmed, cup-shaped solution pits on the surface of high-calcium limestone, south slope of Fremont Peak in the Gabilan Range, Monterey County.



Photo 5. Large solution pits in high-calcium limestone, south flank of Fremont Peak in the Gabilan Range, Monterey County.

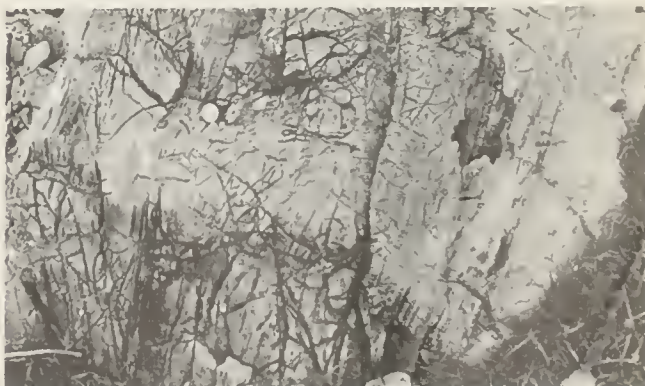


Photo 6. Elephant-skin texture of a typical dolomite outcrop exposed on the southwest slope of Sugarloaf near Natividad, northern Gabilan Range, Monterey County.

calcite, dolomite, aragonite and magnesite. The idea of staining carbonate rocks is not new, and methods were developed over 80 years ago (Lemberg 1887). A test developed by Lemberg is still useful for uncovered thin sections and for rock and mineral grains. The sections or grains are immersed for 10 minutes in cold Lemberg's solution (AlCl_3 and logwood red dye)



Photo 7. Gnarled surface of a typical coarse-crystalline dolomite outcrop showing criss-crossed crevasses formed from weathering of secondary calcite veinlets. The rock has a crude schistosity parallel to the original bedding. The elephant-skin texture, although grosser than in photo 6, is still conspicuous.

and then washed. Calcite becomes coated with aluminum hydroxide, which then takes up the dye. Dolomite is unaffected. Williams, Turner and Gilbert (1954) recommend Lemberg's black ferrous sulfide stain (protected temporarily against oxidation by a film of glycerine) for polished surfaces and thin sections of rock. It is a quick and reliable method, but renders the specimen more or less opaque. A black coat forms on calcite whereas dolomite is not affected.

Rodgers (1940) recommends sample treatment with copper nitrate solution followed by immersion in strong ammonia. A deep blue color is produced on calcite, but dolomite is unaffected. If sample chips are boiled five minutes in copper nitrate, aragonite or calcite take on a pale-blue color whereas dolomite is not stained. Le Roy (1950) describes Meigens (1901) test for distinguishing aragonite from calcite. A polished rock surface or thin section is bathed for 20 minutes in a solution of boiling cobalt nitrate; aragonite stains violet and calcite is not affected. For fine-grained rocks the technique is poor.

Friedman (1959) recommends alizarin red S and Feigl's solution or Harris' hematoxylin and Feigl's

solution for routine classification of calcite and dolomite. These stains are fast, efficient and dependable. Contrast between minerals can be accentuated by etching with HCl prior to staining. Friedman points out that organic dyes stain calcite in an acid solution and dolomite and magnesite in a basic solution. The required immersion time in the solution, acidity or alkalinity and temperature of the solution vary with the composition, porosity, and grain size of the sample being tested. Laboratory facilities are not required for these techniques and they can be done in the field, on hand samples, cores, cuttings, etc.

Mitchell (1956) describes a test using a 0.1 percent solution of alizarin sulfonate in 1.5 N HCl, which stains calcite reddish violet; dolomite is unaffected. Ferric chloride (orange) and silver nitrate (black) have also been used successfully to distinguish between calcite and dolomite, particularly where the stain need be only temporary. Calcite takes the dye, but dolomite does not.

Staining methods, particularly if the cut surface is etched with HCl first, are fast, cheap, efficient, and dependable and can be used to study large surfaces. Many structural, textural, and compositional features in carbonate rocks are on a scale too large to be well studied in thin section. Single grains and unconsolidated material such as carbonate sands can be effectively stained. Stained samples can be used to determine what area or orientation of a sample would provide the most information by thin sectioning.

Some fine-grained and strongly colored rocks do not lend themselves well to staining, as some stains spread across the noncarbonate minerals, are trapped in pore spaces, or else are masked by the natural colors of the minerals to be tested. Other stain techniques have been summarized by Hugi (1945).

Dolomite is denser than calcite (2.85 versus 2.72), and a given unit volume of dolomite is noticeably heavier than an equivalent volume of calcite. The hardness of dolomite, as measured on Mohs' scale, is greater than calcite (3½-4 for dolomite, 3 or slightly less for calcite). The physical properties of some limestone and dolomites are briefly summarized in table 1. Although both calcite and dolomite crystallize in the rhombohedral division of the hexagonal system, crys-

Table 1. Physical properties of some typical limestone and dolomite.*

Physical Characteristic	Limestone	Dolomite	Calcite Marble	Dolomite Marble
1. Unit weight in lbs. per cu. ft.	150-170	150-170	160-170	160-175
2. Specific gravity	2.2-2.8	2.4-3.0	2.6-2.8	2.6-3.0
3. Hardness (Mohs)	3.0	3.5-4.0	3.0	3.5-4.0
4. Hardness (Dorry)	13-14	14-15	13-14	14-15
5. Toughness (in cm. of fall of hammer)	8	9	6-8	7-9
6. Abrasion resistance (L.A. rattler test)	25-30	25-30	30-47	30-50
7. Absorption (percentage)	0.03-12.0	0.03-12.0	0.2-1.0	0.2-1.0
8. Porosity (percentage)	0.2-15.4	0.7-8.5	0.2-0.6	0.2-0.6
9. Compressive strength (p.s.i.)	5,000-28,000	10,000-30,000	24,000-28,000	25,000-30,000
10. Shearing strength (p.s.i.)	1,200-4,000	1,200-4,000	1,300-6,500	1,300-6,500
11. Modulus of elasticity	3,000,000-6,000,000	3,000,000-6,000,000	3,000,000-6,000,000	3,000,000-6,000,000

* Adapted from data presented by Birch, Schaarer and Spicer (1942); Blair (1955 and 1956); Gillson *et al.* (1960) and Windes (1949 and 1950).

tals generally are dissimilar; dolomite crystals have curved crystal faces, whereas calcite crystals have flat crystal faces.

The carbonate minerals are also readily identified by trained technicians using more sophisticated laboratory methods such as chemical analysis, x-ray analysis and the application of optical methods via a petrographic microscope. Under the petrographic microscope, dolomite is distinguished from calcite by higher refractive indices, by differing orientation between cleavages and twin lamellae, and numerous other characteristics. These differences are discussed in detail in any textbook of optical mineralogy and literature on chemical analysis and x-ray methods is extensive.

Within certain limits, calcium and magnesium are easily interchanged in the atomic structure of calcite. In laboratory experiments involving inorganic materials at common atmospheric temperatures and pressures, it has been found that the calcite structure normally can accommodate up to 4 percent of magnesium ions in atomic positions ordinarily occupied by calcium ions. Many organisms secrete aragonite (also CaCO_3 , but orthorhombic in crystallization) or both

aragonite and calcite at various times in their life cycle. Aragonite normally can accommodate fewer magnesium ions in its structure than calcite—ordinarily 1 percent or less in a room temperature-pressure inorganic environment. Chemical and x-ray analyses of many species of shells (Chave, 1954) provide data which indicate that these limitations in substitution of magnesium for calcium in the normal calcite crystal lattice do not hold for organically created calcite and that organic calcite commonly is found containing 12 percent or more MgO . These are metastable and appear to re-crystallize with time to ordinary calcite plus dolomite. By this process, by selective replacement of calcite by dolomite or by metamorphic differentiation, many carbonate rocks become mixtures of calcite and dolomite too closely intermingled to be readily separable. For most industrial purposes, such mixed rock must be crushed and the calcite and dolomite separated from one another before they can be used, thereby materially increasing the cost of the desired product.

The most widely distributed and abundant impurity in both limestone and dolomite is silica (SiO_2) in the form of chalcedony or quartz. Chalcedony is the principal constituent of chert, a chalcedony-rich sedimentary rock commonly associated with carbonate rock deposits. The chalcedony may be disseminated and not readily visible or it may be readily identified in streaks, nodules, lenses or beds. In some California carbonate rock deposits, quartz and feldspar sand grains are abundant, as are miscellaneous rock detritus in sand or silt sizes.

Clay in the form of illite or kaolinite also is a common constituent of impure limestones as well as a widely distributed minor constituent of the purer deposits. In some formations, clay shales and limestones may grade into one another in the form of limy shale and shaly limestone or the friable marls. When conveniently located with respect to markets and transportation such rocks may be valuable sources of material for manufacture of portland cement. For almost all other uses both clay and the quartz-family minerals are deleterious ingredients in both limestone and dolomite.

Another widely distributed impurity in carbonate rocks is organic matter in the form of graphite, bitumens, pollen grains, spores and even gas. Hydrogen sulfide is commonly associated with these. The gaseous materials evidently are trapped in pores between the grains, along cleavages and in minute fractures—particularly in strongly recrystallized, metamorphic carbonate rocks. In the latter, the solid organic products commonly have been converted into dark-colored crystalline graphite. In crystalline limestones valued for their light color, graphite is a deleterious material because it smears badly during grinding and discolours the ground product. A large amount of organic matter can be a harmful ingredient in chemical processes where it may cause scumming of a solution.

Other minor constituents of some carbonate rocks that locally may be troublesome are pyrite, chlorite, glauconite and collophane (in limestone and dolomite) and serpentine in metamorphosed dolomite. None of these are particularly troublesome in California except for pyrite and serpentine. A few California dolomite deposits are ferruginous. Pyrite,

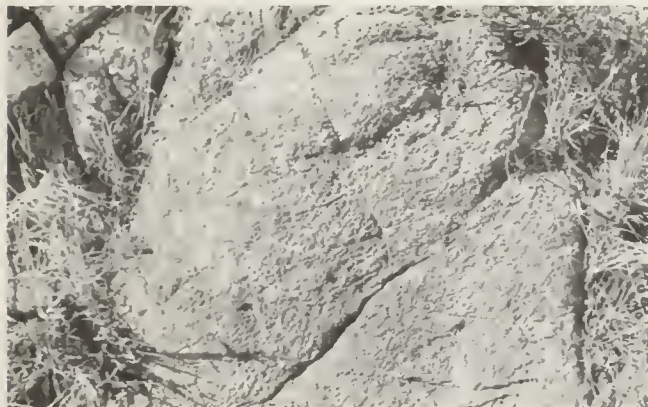


Photo 8. Rough surface produced by differential weathering of cleavage rhombs on an outcrop of very coarsely crystalline, high-calcium limestone, Fremont Peak, Gabilan Range, Monterey County. An equally coarse-grained dolomite would appear similar on weathered surface, but the dolomite cleavage planes often are curved.



Photo 9. Extremely rough, hackly surface of a siliceous limestone outcrop exposed east of Fremont Peak, Gabilan Range, Monterey County, east of the park headquarters. Blebs of weather-resistant quartz and silicate minerals stand out above the calcitic matrix.

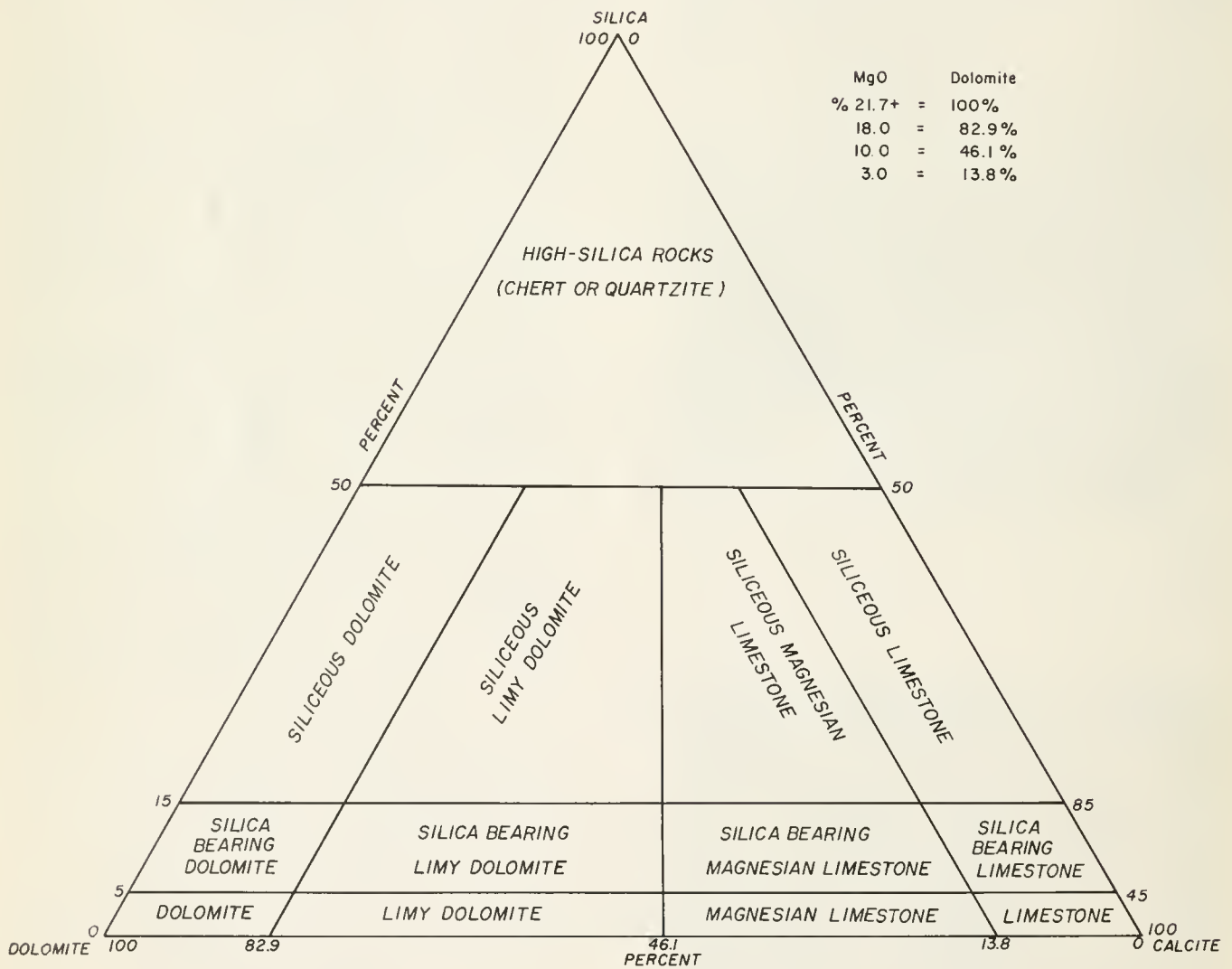


Figure 2. Classification and terminology used for siliceous carbonate rocks.

serpentine and a host of silicate minerals may be introduced into the carbonate rocks by emanations and solutions given off from adjacent invading molten rocks, such as granite. Skarns and tactites, as these rocks generally are called, contain various combinations of the following silicate and metallic ore-minerals: micas, amphiboles, pyroxenes, garnets, epidote-group minerals, serpentine-group minerals (in metadolomites), wollastonite, tourmaline, magnetite, hematite, scheelite, pyrite, etc.

Classification of Carbonate Rocks

To simplify and clarify discussion, carbonate rocks have been classified in various ways, such as origin, texture, chemical composition, industrial usage, etc. In an economic discussion such as this, the chemical and industrial use classifications are the most appropriate. A triangular diagrammatic representation of a chemical classification appears in figure 2. Each apex point on the triangle corresponds to 100 percent of one of the three commonest mineral constituents found in carbonate rocks; that is, calcium carbonate (CaCO_3), commonly present as calcite and rarely as aragonite; calcium magnesium carbonate ($\text{CaMg}(\text{CO}_3)_2$), most commonly present as dolomite; and silica (SiO_2), commonly present as quartz, chalcedony, or chert. (Chert is a water-laid, impure form of chalcedony or chalcedony plus opal, that is a common associate of limestone and dolomite). Each side of the triangle represents the weight percent of each pair of minerals present in the rock. The heavy lines within the triangle delimit the various compositional fields with which each printed name is associated.

Figure 3 is a quadrangular diagram or schematic chart showing the names of the principal compositional varieties of limestone and dolomite and their

principal industrial uses. The magnesium content (expressed as MgO) increases from 0 to 21.7 percent left to right across the chart. The horizontal bars indicate the ranges in composition allowable for these uses. Additional compositional requirements are listed at the bottom of the chart.

In industrial practice, "high calcium" limestone is roughly synonymous with "chemical grade" limestone and signifies a rock containing 95 percent or more of CaCO_3 . In California, limestone containing 97 to 98 percent CaCO_3 is available to most markets, so rock of this quality becomes the measuring stick of quality of "high calcium" limestone.



Photo 10. Dark chert nodules and replacement patches of chert stand out in striking relief above the lighter-colored limestone matrix, McCloud Limestone, Potter Creek arm of Lake Shasta, Shasta County.

PERCENTAGE OF MgO CONTENT					
0	1	3	10	18	21.7
LIMESTONE		MAGNESIAN LIMESTONE		LIMY DOLOMITE	
HIGH PURITY	HIGH CALCIUM				
CEMENT ³					
SUGAR REFINING ⁴		STEEL FLUX (blast furnace) ¹			
STEEL FLUX (open hearth) ²			LIME (magnesian)		
CHEMICAL USE		AGRICULTURAL LIME			
GLASS MANUFACTURE ⁶					
LIME (high calcium)					
					REFRACTORY DOLOMITE ⁵

1 SiO_2 < 5%, preferably < 3%, Al_2O_3 < 2%, P_2O_5 must not exceed trace amounts (ie, 0.005–0.006%)

2 P_2O_5 must not exceed trace amounts

3 Total alkalis < 0.5%

4 SiO_2 < 1.0%, Fe_2O_3 < 0.5%

5 SiO_2 , Fe_2O_3 and Al_2O_3 not to exceed 10% each

6 Fe_2O_3 < 0.05%, preferably < 0.02%

Figure 3. Suggested nomenclature for non-siliceous carbonate rocks. The nomenclature is based on the MgO - CaO - SiO_2 (dolomite-calcite-silica) content of the rocks. The diagram, which makes use of the MgO subdivisions in figure 2, also shows the principal use categories of the rocks.

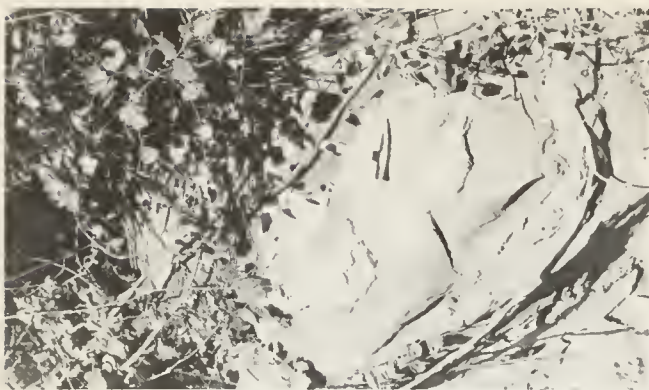


Photo 11. White-weathering chert replacement patches stand in relief above a matrix of fine-grained limestone of the McCloud Limestone, Potter Creek arm of Lake Shasta, Shasta County.

Dolomite, which has a much more restricted use in California, must run at or above 20 percent MgO (near to "high purity" or theoretical dolomite) to be marketable as a chemical or refractory raw material. With increased use, dolomite having 18 to 20 percent MgO may be marketable in the future. A small amount of magnesian limestone is quarried and processed into lime for plaster but in general, neither magnesian limestone nor limy dolomite can be sold in any volume in California except as building stone, for aggregate, ashlar or cut stone use. If a siliceous limestone contains less than three percent MgO it may be useable in portland cement even if the CaCO_3 content is as low as 82 percent. Most grossly impure carbonate rocks are useful only as stone.

The terms marble and crystalline limestone deserve brief discussion because they have figured in several prominent law suits in recent years and because freight rates differ between "limestone" and "marble". Strictly speaking, marble is a crystalline limestone or dolomite that will take a sufficiently high polish to be useful as an ornamental stone. However, limestone that is not noticeably crystalline but that takes a polish is also sold as marble. Nearly all limestones, of course, are crystalline to some degree but the crystalline character may not be apparent to the naked eye. People who have little knowledge of industrial materials have tended to use marble and crystalline limestone interchangeably. Consequently, custom and usage have tended to render these synonymous. In this report, the term marble is confined to carbonate rocks that will take a polish and, therefore, have particular industrial applications.

Useful Properties of Carbonate Rocks

All of the rocks composed predominantly of carbonate minerals are convertible into metallic oxides and carbon dioxide (CO_2) gas if heated beyond the critical temperature of dissociation for the constituent minerals. The dissociation temperature range for calcite or pure limestone is 725° to 1000°C.; other carbonate minerals decompose at temperatures ranging from 545°C. (for dolomite) to 1500°C. Lime (CaO or quicklime) is the solid dissociation product derived when limestone is calcined and the carbon dioxide driven off. Magnesian

lime (a mixture of CaO and MgO) is derived from calcination of dolomite or magnesian limestone, and magnesia (MgO) is derived by calcination of magnesite or by separating the MgO from CaO of calcined dolomite. These metallic oxides combine readily with water, with evolution of much heat, to produce hydrated lime (Ca(OH)_2) and hydrated magnesia (Mg(OH)_2) or mixtures of these hydrates. Many chemical industries use carbonate rocks as a source of carbon dioxide gas. Because of its lower heat of dissociation dolomite is a cheaper source of CO_2 than limestone, but because high-calcium lime derived from limestone is a much more valuable and saleable byproduct than the magnesian limes derived from dolomite or magnesian limestone, high-calcium limestone is more commonly used.

The suitability of a carbonate rock as a source of lime varies considerably according to its texture and structure as well as for reasons not easily explained. In some industrial processes the rock must retain its lump shape during the calcination process. Medium- and coarse-grained or complexly jointed and fractured rocks will not do for such purposes. The rate and evenness of hydration also varies considerably among various industrial limestone deposits, again for reasons not readily apparent under laboratory testing. It is common practice for lime plants to make mill-runs of all carbonates offered for use, as this yields the most practical results.

In recent years the physical properties of carbonate rocks pertinent to their use as building materials (as support for buildings) and to their behavior in response to seismic and man-made shock waves has been investigated widely. A brief review of these as well as of supplemental sources of information may be found in Gillson *et al.* (1960, p. 136-140). The thermal expansion of limestone, for example, is very low and its radioactivity usually is very low. Comparative test data are available for such characteristics as thermal conductivity, thermal expansion, transmission of wave velocities, heat capacity, electrical resistivity, compressive strength, modules of elasticity, toughness, soundness, abrasion resistance, shearing strength, absorption of liquids and gases, hardness, unit weight, specific gravity and others. As the degree of deformation to which carbonate rocks have been subjected varies widely in California because of repeated tectonic activity, the utility of the state's numerous limestones for building materials varies broadly.

Other important properties of the carbonate rocks are their ability to neutralize acids, condition clay soils and act as a base exchange vehicle and a flux in ferrous and non-ferrous metallurgy. These are more fully discussed in Chapter 4.

Metamorphism of Carbonate Rocks

Because California has a long history of tectonic activity, most of its deposits of carbonate rocks have been metamorphosed to some degree—that is, they have been changed by application of heat and pressure and commonly by shearing stress as well. A majority have been re-crystallized—mainly with notable coarsening of texture. This reduces the utility of the rock

for some purposes, such as sugar refining, steel manufacturing, glass manufacturing, etc., where decrepitation (disintegration under heat) is undesirable. On the other hand, recrystallization of limestone into coarse crystals commonly yields a rock easily crushed into rhombic particles. These are desirable in some crushed products, such as paint fillers. In some cases, metamorphism reduced the grain size of a previously coarse-grained crystalline limestone by mylonitization (natural crushing under high pressure), but such deposits are uncommon. Crystalline limestones are the rule rather than the exception among California deposits.

The disseminated organic matter common in limestones generally is driven off to varying degrees during metamorphism or is concentrated into grains as crystalline graphite. A color change from black, brown, blue-gray or gray to white is a common and economically useful result of metamorphism. California has no chalk deposits, and only a few impure unmetamorphosed limestones (in eastern Riverside and Imperial Counties) are white. Organic constituents, such as hydrogen sulfide and various hydrocarbons apparently aid in the process of re-crystallization, and many coarsely crystalline limestones are ferrid. Organic matter may make up as much as 4 percent of some California limestones and crystalline limestones.

Inasmuch as many carbonate rocks are metamorphosed near to and under the influence of incoming molten igneous rocks, a host of contact metamorphic minerals may be introduced. Silica, water, iron, magnesium, boron, alumina and the alkalis are among the more common ingredients introduced. Various combinations of minerals may form depending upon the temperatures, pressures, and shearing stresses present during metamorphism. Garnets, diopside, wollastonite, tremolite, epidote, zoisite, scapolites, forsterite, serpentine, vesuvianite, brucite, phlogopite, actinolite, hedenbergite, cummingtonite, chondrodite and other humite group minerals and feldspars are all common in various California contact metamorphosed carbonate rocks. Deposits such as those at Crestmore, Riverside County, may yield several hundred mineral species. Resultant textures sometimes are extremely coarse-grained, with crystals several inches to several feet in longest dimension. Contact metamorphic carbonate rocks are troublesome in some California operations because they tend to lower the grade of some blocks of rock to the extent that more costly selective mining is necessary.

A few large California deposits of carbonate rocks appear to have undergone metamorphic segregation of calcite and dolomite during plastic flow and shearing stress in rocks consisting originally of intimately intermingled calcite and dolomite. In such deposits, clots and streaks of pure calcite are found in a matrix of dolomite and vice versa. The proportion of clots and streaks to matrix commonly is on the order of 1:2 or 1:3. Grain diameters observed in such rocks commonly range from 0.3 to 1.0 mm. Consequently, these rocks would be adaptable to low-cost beneficiation. It might prove cheaper to utilize such mixed deposits located near to markets than to use higher grade deposits at considerably greater distances from markets.

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CHAPTER 2

CHARACTERISTICS THAT GOVERN THE QUALITY AND DISTRIBUTION OF CARBONATE ROCKS

By Oliver E. Bowen

Sedimentary Controls

Inasmuch as carbonate rocks are predominantly of marine sedimentary origin, variations in the sedimentation that was responsible for accumulation of the carbonate formation (or formational subunit) are the principal causes of primary variation in the commercial quality of most carbonate rock deposits. Currents induced by storms or by seasonal changes and the resulting storm and seasonal influxes of detrital materials may interrupt an otherwise orderly deposition of carbonate material. The result is deposits of carbonate rocks interlensed, interfingered and interstratified with those of clay, sand, silt and even gravel. Conditions sometimes favor a small but steady influx of detrital material of non-carbonate character, and silty, sandy or clayey limestones result. Great thicknesses of such rock are known in Permian and Carboniferous sections in Inyo County, California—notably in the Owens Valley and Keeler Canyon Formations.

Metamorphism and Structural Controls

A great many California sedimentary sections containing carbonate rocks have been strongly affected by regional metamorphism so that their original sedimentary character is obscured if not obliterated. Claystones recrystallize to slate or schist, sandstones and siltstones to micaceous or feldspathic quartzites, limestones to crystalline limestone or marble, cherts to quartzite, and so on. Their intermixed condition remains, however, a function of the original sedimentation. Rocks so altered commonly have been complexly folded and sometimes faulted as well, so that exploration for carbonate rock deposits must include regional and local structural studies as well as sedimentation studies.

Contact metamorphism, that is, those lithologic changes resulting from massive influxes of molten material—such as emplacement of a granitic stock or batholith—can result in introduction of large amounts of impurities into a previously high quality limestone or dolomite deposit. Fortunately, these influxes tend to be localized and commonly do not destroy the utility of a given body of carbonate rock. Siliceous and metalliferous minerals are the types of impurities most likely to be introduced during contact metamorphism.

Dolomitization

Dolomite—the double carbonate of calcium and magnesium—contains a high proportion of magnesium. Although necessary in some industrial proc-

esses, magnesium is highly detrimental in others. Hence, identification of dolomite in a carbonate-rock deposit and recognition of the factors that control its presence are of prime importance in evaluation of carbonate-rock deposits. As dolomite is less soluble in rainwater than calcite, dolomite tends to stand out in relief from a surface on which both dolomite and limestone are exposed. The observer must, of course, be able to distinguish the dolomite from introduced quartz or silicate minerals. The solution pits that develop on the surface of a high-calcium limestone tend

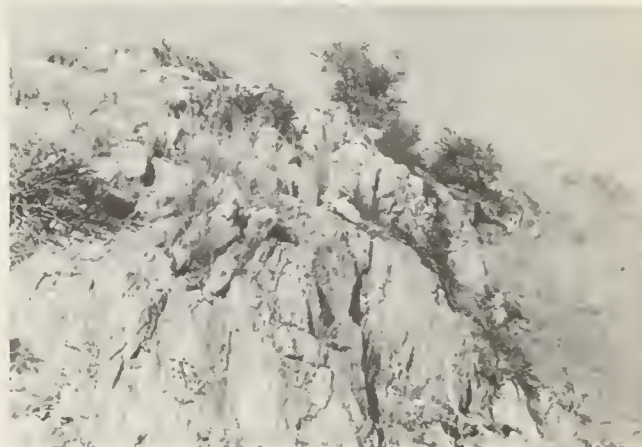


Photo 12. A steeply dipping sequence of interlaminated limestone, dolomite and siliceous limestone in the Sur Series (Paleozoic(?)) on the south slopes of Fremont Peak, northern Gabilan Range, Monterey County. Layers of both siliceous limestone and dolomite stand out in relief above the layers of purer limestone.

to be cup-shaped, sharp-edged and well developed (see photos 4 and 5), whereas those on dolomite are generally poorly developed, irregular and dull-edged. Furthermore, solution cavities on dolomite commonly are developed in crisscrossing linear patterns controlled by joints and fractures, and the resultant texture resembles an elephant's skin. Limestones seldom if ever develop such surface textures.

Many California dolomites are slightly higher in iron than the limestones with which they are associated. Consequently, they commonly weather a pale buff or even a noticeable brown in contrast to the usually white to pale blue-gray limestone with which they are commonly associated. Many California dolomites and dolomite limestones also tend to have a higher silica content than the adjacent limestone, a fact that further

reduces the susceptibility to weathering and enhances slightly the relief of weathered surfaces. Unfortunately, most of the readily apparent differences between surface textures of limestone and dolomite do not apply on freshly broken surfaces, so the differences are of little value to the quarryman in quality control problems. Chemical analysis or staining with such chemicals as alizarin red, cupric nitrate or ferric chloride are the most suitable methods for distinguishing calcite-dolomite proportions in freshly quarried samples or in drill cores (see p. 19-20 of this Bulletin).

In most cases dolomite forms by chemical replacement of limestone (calcite) on the sea floor not very long after original deposition. Replacement of this type follows no set pattern and may be partial or complete; i.e., a given bed may have replacement patches of dolomite dispersed through otherwise calcitic limestone, or the entire bed may be replaced by dolomite. In California, as well as in numerous other parts of the world, some dolomite is also formed during mountain building or during emplacement of hydrothermal metalliferous deposits long after deposition of the host formation. Such deposits commonly are fracture- and fault-controlled and may form a recognizable pattern within the carbonate-rock mass. In many cases they cut across other dolomite bodies formed by sea floor replacement.

Weathering and Erosion Controls

In most California climates, carbonate rocks weather and erode less readily than the schist and granitic rocks with which they commonly are associated. Hence the carbonate rocks tend to stand out boldly in relief and may give a false impression to someone estimating reserves. In areas where schist interbeds and granitic intrusions may be numerous, accumulations of talus and/or soil mantle may mask them more than the associated carbonate rock. Presence of granitic rocks and schist in an apparently homogeneous mass of carbonate rocks generally may be detected by the

appearance of granitic and schist debris in the soil and by the distribution of debris-filled depressions worn into these more easily weathered and eroded rocks.

Other Characteristics

Adjoining limestone and dolomite bodies commonly may be distinguishable one from the other because of differences in average grain size, variations in grain size, differences in density and even differences in grain shape. More often than not, dolomites are finer grained, denser and heavier than the limestones with which they are associated. These features together with the weathered color (cream through buff to brown), shape and distribution of solution cavities and noticeable relief of dolomite above calcite matrixes offer an alert observer a surprisingly accurate way of estimating the probable chemical content of carbonate rock deposits.

Formation Age as a Prospecting Tool

In California, carbonate formations older than Devonian have been found to be made up predominantly of dolomite. Rocks younger than Devonian contain a much smaller proportion of magnesium-rich carbonate rocks. Dolomite deposits of economic significance are virtually unknown in the Mesozoic and Tertiary formations of California, although widespread Tertiary lakebed dolomite and magnesite of small consequence are present in the Mojave Desert. The desert deposits are believed to have been formed under the influence of volcanic springs. The Devonian and Triassic Periods on the whole were particularly favorable for accumulation of high-grade limestones.

Most of the better and larger dolomite deposits occur in Ordovician, Cambrian, and Upper Precambrian sections. Many high-grade deposits of limestone occur in Permian and Carboniferous sections in California, but a notable number of these are interbedded with magnesian limestones, and many are siliceous as well.

CHAPTER 3

MINING, PROCESSING AND BENEFICIATING CARBONATE ROCKS IN CALIFORNIA

By Oliver E. Bowen, James R. Evans, and Clifton H. Gray, Jr.

Unlike the middle west or southwest parts of the United States, California has few flat or nearly flat-lying limestone-bearing formations. More often than not, California limestone bodies are thick, rather structureless masses, unmarked by distinctive horizons and somewhat variable in chemistry. Commonly, such bodies are mined en masse, and the problems of chemical variation are overcome by blending the various grades of rock. Igneous intrusions and interbeds of rock of non-carbonate character often necessitate considerable selectivity during quarrying. Land-surface relief is often considerable and in some cases extreme. Consequently, one cannot mine a few select beds of rock over large acreages. Five deposits currently are mined underground—one to an inclined depth of 1300 feet. One major cement plant is supplied almost wholly by underground mining.

Acquisition of Mineral Properties

Many deposits of carbonate rock are privately owned, title to these deposits having passed from public to private ownership under various land and mining laws. Where the mineral rights have not been separated from the surface rights, acquisition is simplified, as negotiations need be carried on with only one owner. Generally, these deposits are acquired by outright purchase of the property. An alternate method of acquisition could be by lease and operating agreement.

When mineral rights have been separated, either at the time of or subsequent to patent, it is important that the prospective purchaser or lessee determine the ownership of the carbonate rocks before executing a contract. Where minerals have been separated subsequent to patent, it is not always clear whether carbonate rocks and other commonly occurring industrial minerals were segregated or remained with the property. In those instances where patent was issued without the mineral rights, the ownership of the commonly occurring industrial mineral may be even more difficult to determine. This difficulty is due primarily to the difficulty of separating rock deposits into those locatable and those that are common varieties. Common varieties deposits are generally believed to have passed to patent with the surface rights.

A large number of carbonate rock deposits exist on public lands and on patented lands with the minerals reserved to the United States. These deposits can be located and patented provided the lands on which they lie are open to mineral entry and provided the

deposits are utilized in the metallurgical, chemical or cement industries. Recent Department of Interior decisions indicate a carbonate rock utilized for ornamental stone may be locatable provided it has some special property not possessed by similar stone. One way of demonstrating this special property is to show that the rock being located commands a substantially higher price in the market than common varieties stone. Admittedly this definition is not easily understood but it reflects the Department's attempt to define what is and what is not a common variety. For any mining claim located for carbonate rock to be considered valid by the Department, the locator or owner must be able to demonstrate that a market exists for carbonate rock from the claim.

Locators must be citizens of the U.S. or at least aliens who have taken out their first naturalization papers. Nationals of other countries would have to be associated with citizens of the U.S. in order to operate properties located on public domain.

Carbonate rock deposits utilized only as a source of road base or riprap cannot be located but may be purchased under contract from the Federal agency having administrative control over the land on which the deposit lies.

A few carbonate rock deposits, such as the oyster shell deposits on tide lands, are owned by the State and may be acquired by competitive bidding, or by preferential lease. The preferential lease is predicated on a prospecting permittee discovering a deposit on lands not known to contain commercial deposits.

The manner of locating and holding mineral claims in California is discussed in *Legal Guide for California Prospectors and Miners*, obtainable at any Division of Mines and Geology office. A still more complete treatise is *American Mining Law*, by A. H. Ricketts, California Division of Mines Bulletin 123, published in 1943. This is now out of print and is available only for reference at the various Division of Mines and Geology offices and at many large libraries. The problem of the "common varieties", as redefined in 1964, is discussed in *Mineral Information Service*, November 1962, p. 8. Limestone is dealt with specifically.

The most comprehensive and most nearly up-to-date treatise on mining law is *The American Law of Mining* published in 1964 and supplemented annually by the Rocky Mountain Mineral Law Foundation through Matthew Bender and Company, New York and San Francisco. Since 1955 the Rocky Mountain

Mineral Law Foundation has also published, through Matthew Bender and Company, an annual volume of Proceedings of the Rocky Mountain Mineral Law Institute, which includes comment on recent cases in mining laws and trends. Current reports on legal matters pertaining to mining are published by the Gower Federal Service-Mining, a publication of the Rocky Mountain Law Foundation.

Capital Expenditures

An individual or firm contemplating putting a limestone or dolomite property into operation is faced with several alternatives. He may quarry, process and market the rock himself or he may engage in one or more of these phases and delegate the others to concerns better able to carry them forward. Selling or leasing generally involves little or no capital outlay for the owner, whereas any phase of production and marketing may involve substantial capital investment. Royalties paid on limestone and dolomite in California range from 10 cents per ton, for large volume operations, to 50 cents or even \$1 per ton for small ones. Most fall within the range of 10 to 25 cents per ton.

Among the smaller operators who have avoided large capital expenditures are those who employ portable crushing-sizing-loading units, which are rented or leased from a machinery dealer or from another quarry operator, or are purchased under long-term financing. Lime plants and most fine-grinding circuits are costly and conventional portland cement plants cost up to 12 dollars or more per barrel of annual rated capacity. In Europe, small vertical cement kilns (annual rated capacity about 100,000 barrels) have been designed, one of which has been erected in New York state. These cost in the neighborhood of 6 dollars per barrel of annual rated capacity. In cases where an operator controls a moderately sized ready-mix concrete marketing area, there has been considerable incentive for building installations of this type in California. Because of the narrow margin of profit and because of the threat of antitrust litigation, none has been built.

Problems in Sampling Limestone and Dolomite Deposits

The suitability of a limestone or dolomite deposit for most industrial uses is dependent primarily on its chemistry. Therefore, adequate sampling for chemical analysis is of prime importance. Sampling, which normally should involve core drilling and surface sampling, as well as chemical analysis, is expensive, and the geologist too often has to work with limited exploration funds. Consequently, his choice of sample locations and method of sampling are particularly vital if he is to judge what the quality of the quarry-run rock is likely to be and whether or not selective mining will be necessary.

A geologist experienced in carbonate rocks may be able to make a useful evaluation of a deposit by taking only a few surface samples from selected points determined by the geological conditions in the deposit. During detailed examination, the probable size, shape and attitude of the masses of uniformly good rock are determined together with the areas of bad or suspect

rock—particularly in the less complicated deposits. Selection of a few five-pound spot samples from the various classes of rock present sometimes is sufficient. However, such limited sampling by inexperienced personnel more than likely will prove to be unsatisfactory.

The pattern and frequency of surface and subsurface sampling is dependent to a great extent on the continuity of outcrop and the kind of overburden present. Under most climatic conditions in California, presence of an extensive masking residual soil overburden probably indicates that the deposit contains a substantial proportion of granitic intrusive rock or else much included schist, slate or other rock of non-carbonate character. This generalization does not hold true for deposits newly exposed by erosion after burial under volcanic ejecta or transported sediment. Hence the recognition of the kind of overburden present and the environment in which it formed can be important in estimating the subsurface continuity of the deposit and thus in selecting an adequate sampling procedure.

Most dolomites originate by replacement of pre-existing limestone—most commonly on the sea floor during accumulation, but also by fluids mobilized long after burial during periods of mountain building and emplacement of granitic rocks. The dolomite replacement may be more or less complete, bed by bed, and be found in sheet-like masses easy to delineate, or it may be patchy and sporadically distributed through the limestone matrix or host rock and be difficult to identify. The most difficult deposits to evaluate by sight identification are those that contain rock within the ranges of 5–10 percent MgO and 15–20 percent CaO. A trained observer can learn to distinguish between most high-magnesian dolomites and high-calcium limestones. Such distinguishing characteristics are dealt with at some length in the chapters entitled "Mineral Content and Distinguishing Characteristics of Limestone and Dolomite" and "Characteristics That Govern the Quality and Distribution of Carbonate Rocks."

A flat-lying or gently dipping, apparently homogeneous deposit is commonly sampled by laying out a grid pattern of sample locations. The grid spacings usually are governed by the specifications that must be met when the rock is marketed and upon the availability of exploration funds. Ideally, a five- to 10-pound typical spot sample is collected; a hand specimen is retained for reference and the remainder pulverized and quartered down to a 300 gram sample for use of the analyst. Also ideally, a second composite, small-chip sample of similar size, is collected at each grid station over an area several yards square. This is similarly quartered, analyzed, and compared with results for the type spot sample. If surface analytical results are promising, supplementary vertical core-drilling is commonly adopted on a cross-shaped or grid pattern to test the deposit at depth. Channel samples, continuous chip samples cut along some line for a particular footage interval (five or 10 feet is common), are also often employed for surface sampling or on a supplementary or substitute basis. The depth and spacing of the holes usually is dependent upon the known facts concerning the local geology and upon the availability of exploration funds. The drill cores are suitably boxed, marked, and referenced. The cores are split; half

the core is retained for reference, and a suitable depth interval is chosen. The other half of the core is pulverized, quartered down into samples representative of each depth interval, and a suitable fraction of each quartered sample (100–300 gram) is made available for analysis. In heterogeneous deposits, a continuous depth-interval sampling and analytical procedure may be necessary. More commonly, however, such continuous procedures are unnecessary.

More often than not, California deposits are steeply dipping and non-homogeneous so that conventional sampling procedures must be altered to best evaluate the variations in the deposit. Drill holes inclined perpendicularly to the bedding may have to supplant the more easily drilled vertical holes so that the maximum stratigraphic thickness can be tested in the shortest possible footage. Some areas of rock which are obviously too impure can be left out of the sampling pattern and borderline bodies can be more intensively sampled than areas of good or bad rock.

Mining Methods

Most California limestone and dolomite deposits are situated on hills where they can be readily quarried from level benches cut into the hillsides. In some places, however, it has been necessary to utilize pits sunk well below local base level, with resultant higher quarrying costs. There are four large, and one small, underground mines from which limestone, dolomite, or both are obtained. At Davenport, Santa Cruz County, there is one large glory hole operation where the haulageways and part of the rock-storage facilities are underground. Underground mines are found at: the Crestmore cement operation of American Cement Corporation, Riverside County; U.S. Lime Products Division of The Flintkote Company, Sonora, Tuolumne County; the El Dorado Limestone Company, Shingle Springs, El Dorado County; the Diamond Springs Lime Company near Auburn, El Dorado County; and the dolomite operation of Premier Marble Products near Keeler, Inyo County. Other underground mines have operated intermittently at Felton, Santa Cruz County, and near Keeler, southeast of Premier's operation. Diamond Springs Lime Company's mine was originally a glory hole operation under a previous operator.

With a few exceptions, California limestone and dolomite deposits are so tenacious that blasting is required to break the rock into fragments of suitable size for handling and processing. Two notable exceptions are the Skyline limestone deposit near Crystal Springs Lakes in San Mateo County (currently inactive) and the Westvaco dolomite deposit near Hollister in San Benito County. At both of these deposits, the rock has been shattered by faulting in the San Andreas fault zone, so that little or no blasting is required to break the rock.

The cost of underground mining of limestone generally is upwards from 75 cents per ton of rock delivered to the mill.

Quarrying

In common bench-quarrying practice in California, 20-, 30-, and 50-foot or even larger bench spacings (vertical distance between floor levels or height of the working face) are adopted, depending upon the topography, distribution of various grades of rock in the

deposit, safety factors, and other considerations. A line of holes commonly is drilled at a suitable distance back of the working face, from the top of the face down to the approximate level of the quarry floor. The spacing of these holes and the distance from the working face is dependent upon the type of explosive being used, the breaking strength of the rock, the degree of fragmentation desired, and other related factors. The diameter of the holes ranges from three inches to more than nine. Explosives manufacturers are continually improving explosives and blasting practice, which are adaptable to the needs of producers of carbonate rocks. Development and use of drill rigs capable of making large inclined blast holes is a renewed application of principles known since 1918. Some companies are contracting most of their blasting operations to explosives companies. Costs of quarrying limestone range from 40 to 80 cents per ton in very large operations to one or two dollars or more in small ones for each ton of rock delivered to the mill.

At many California operations near population centers or transportation lines, it is desirable to blast as infrequently as possible. In such cases, very large masses are broken in a single blast. It is not uncommon to break a million tons or more of rock at a time. Secondary blasting is often avoided by use of large drop balls weighing from 1,000 pounds to several tons attached by cable and boom to an electric, diesel, or gasoline powered winch. The ball is dropped onto such pieces of broken rock as are too large for easy handling.

Underground Mining

Room and pillar, shrinkage stope, top slicing and block caving methods have been successfully employed in California limestone and dolomite mines. U.S. Lime Products Division of The Flintkote Company at Sonora, Tuolumne County, employs a modified room and pillar method, workings being driven from a vertical shaft, down over 500 feet. The rooms commonly are 50 feet wide and several hundred feet long. Some reach a height of 50 feet. The deposit is a nearly vertical tabular mass of carbonate rock 300 feet wide and more than 1,000 feet long. It has been mined to a depth of more than 400 feet and a strike length of more than 1,000 feet.

The El Dorado Limestone Company mine near Shingle Springs, El Dorado County, employs the shrinkage stoping method. Limestone occurs in two nearly vertical (80° to vertical), tabular to slightly lenticular, subparallel masses ranging from a few feet to nearly 50 feet apart. The east mass averages about 60 feet wide and the west 40 feet wide. Entry to the mine in the east mass is by a three-compartment 80° inclined shaft 1,200 feet deep. Early in 1964 stopes were being developed on the 1,160-foot level but most of the mining was on the 960-foot level. Completed shrinkage stopes have been developed in the thickest parts of the each mass, the largest being 600 feet long, 70 feet wide, and 300 feet high; others are smaller. The haulageways to the shaft are 20 feet wide and eight feet high. Short crosscuts driven perpendicular to the main haulageways connect with draw points from the stopes. The limestone bodies have an economic limit in length of approximately 1,400 feet, almost all of this being south of the shaft.

Prior to 1954, the Crestmore mine of Riverside Cement Company (now the Riverside Division of American Cement Corporation) used the block caving method of mining. Entry was effected through a five-compartment vertical shaft 350 feet deep. The caved blocks were about 200 feet high, 200 feet wide and 240 feet long. Blocks were isolated by cutoff shrinkage stopes at both sides and ends. The haulage level consisted of parallel drifts driven on 70-foot centers and the mining level consisted of parallel drifts driven on 35-foot centers (Robotham, 1934, p. 1-20; Tucker and Sampson, 1945, p. 174; Wightman, 1945, p. 215-224). Access and ore-pass raises connected the mining and haulage levels. Two limestone masses have been worked in the underground mine. These are 200 to 300 feet thick and dip underground at angles of between 30° and 45°. The two ore bodies are separated by several hundred feet of granitic rock.

Early in 1954, mining by block caving ceased and rock was supplied to the cement plant from surface quarries while a new mine was being developed. Placed in operation in 1956, the new mine will ultimately reach an inclined depth of 1500 feet. Mining is now done by the room and pillar method, rooms being 60 feet wide, 90 feet high and running the full width of the ore bodies, about 200 feet. For several years rock was removed from the mine over a spiral truck haulage way 30 feet wide with a vertical clearance of 20 feet and a grade of 10 percent (Persons, 1955, p. 76-77). The trucks were electrically driven and conventional electric shovels were used for loading. More recently rock removal has been over belt conveyors.

Room and pillar mines entered by sidehill adits have been operated for dolomite near Keeler, Inyo County, and for limestone near Felton, Santa Cruz County.

Transportation

Rock is transported from the quarry to the processing plant or to market by truck, rail, belt conveyor, pipeline (as slurry) and various combinations of these methods. Specially designed rear- and side-dump trucks, trailers and railroad cars are being devised to facilitate transportation and reduce handling costs. The trend is toward larger capacity rigs except at the small operations. Loading is accomplished by electric shovels, gasoline-powered skip loaders, bucket and belt conveyors and even by simple bulldozer and ramp methods. Among new installations, the trend has been toward establishing primary and secondary crushing installations, chute-loading facilities and some sizing (screening) installations close to the quarries.

California is a have-not state where limestone deposits near tidewater are concerned. In fact, few deposits of any consequence are very close to water-freight facilities anywhere on the Pacific Coast of the United States. Because of high truck and rail-freight haulage costs, tidewater limestone-consuming industries are taking a long look at water-freight possibilities. With large ships and automatic loading and unloading devices, limestone can be handled for 1 or 2 mills per ton mile versus 2 or 3 cents per ton mile by rail or 4 to 7 cents per ton mile by truck. Under these conditions, certain Monterey County near-tidewater deposits may be brought into production, and Canadian and Mexican limestone may possibly

become competitive with domestic sources at California ports. Canadian limestone already is in use in coastal and inland port areas of Oregon and Washington.

Processing

For a great many purposes, limestone and dolomite processing simply involves crushing and sizing. Where certain trace impurities, such as iron oxide coatings, or small clay fractions are to be removed, a washing and scrubbing circuit may be added. In small operations, particularly those that may be temporary, it has become common practice to use portable combination units which consist of a jaw-crusher and screens or a jaw-crusher, hammer mill and screens together with recycling and loading belt or bucket-type conveyor-loaders. Several firms make units of this sort mounted on wheels. Permanent installations are, of course, more flexible and versatile in many respects.

Where the end-product is to be finely ground, more elaborate equipment is necessary and much greater capital outlay is required. Various combinations of cone crushers, roll crushers, impactors (hammer mills), tube mills, rod mills and ball mills are used for secondary and fine grinding. Sizing may be accomplished by various combinations of rotating screens (trommels), vibrating screens, rake classifiers, hot dry-screening installations, air separators and the like (Perry, J. H., et al., 1950; Pit and Quarry Handbook, Taggart 1945).

Beneficiation

As the result of rising transportation and deposit acquisition costs, urbanization and other economic factors, a number of California and other U.S. plants that utilize carbonate rocks have turned to upgrading the marginal and low-grade parts of their deposits by beneficiation procedures. Recent advances in technology have greatly encouraged the trend and considerable company-sponsored research has been done successfully. Separation of limestone and calcite particles from excessive amounts of impurities, such as chert (chalcedony), granitic rock fragments, feldspar, quartz and micas through froth flotation, has been particularly successful (Herod, 1964; Kleiber and Meisel, 1964). Both limestone and dolomite have been successfully separated from one another or from siliceous and aluminous impurities by heavy media separation. Electronic color-sorting or reflectance-sorting of limestone and various impurities by use of photoelectric cells has also proven its worth—particularly for producers of high-reflectance white rock but also at deposits where the color differences or degree of reflectance among the desired separation products is less obvious (Peirson, C.U., 1964).

Other techniques that have been tried with various degrees of success include removal of siliceous impurities by calcining, slaking and screening, and separation by means of differential grinding (Kleiber and Meisel, p.158-159). Other scanning techniques in the experimentation and development stages include the use of infra-red, ultraviolet, and gamma radiation (Chew, 1964, p. 29).

Manufacture of Lime, Magnesite, Magnesian Lime, and Carbon Dioxide*

Carbonate rocks are important sources of metallic oxides and carbon dioxide in California, although in some operations one or more of the end products goes to waste. Calcining (burning) carbonate rocks at temperatures ranging from 545°C. to 1500°C., depending upon the minerals involved in the desired purity of the end product, converts them to a metallic oxide (or oxides) and carbon dioxide gas. Under most conditions, the temperature at which carbon dioxide begins to be driven off from limestone is about 725°C., but there is some variation because of impurities and physical characteristics, such as particle size and the internal structure of the particles. For example, the temperatures of dissociation of dolomite have been found to be considerably lowered by prolonged grinding (Bradley, F. W., et al., 1953, pp. 207-217).

For most carbonate minerals, there is some temperature range at which carbon dioxide gas is given off in greatest volume, or there may be two or three peaks of dissociation, as in ankerite or dolomite. For calcite limestones, the major evolution of gas is between 900°C. and 1000°C. A kiln temperature of about 1200°C. is maintained in burning most high-calcium limestones, as well as in burning magnesian limestones that have a moderate magnesium content, to insure complete dissociation. The time required to convert limestone to lime at such a temperature depends on the particle size of the rock being calcined and on the type of kiln. In the old single-charge kilns using wood or charcoal fuel the burning time was as much as four days, and the resulting product commonly contained unburned residue. Modern kilns have reduced the burning time to a few hours, operating with more even calcination and leaving very little uncalcined residue.

Pure magnesite is largely converted to magnesite (MgO) and carbon dioxide at temperatures between 545°C. and 835°C., the maximum dissociation effect being at about 700°C. However, a small amount of CO₂ may remain under considerably higher temperatures, and both magnesite and dolomite (half the composition of which can be expressed as magnesium carbonate) commonly are burned at kiln temperatures as high as 1500°C. The dissociation range for pure dolomite has been determined experimentally as 825°C. to 945°C. with maximum effects at 810°C. $\pm 15^\circ$ and 940°C. $\pm 25^\circ$ (Haul and Haystek, 1952, pp. 166-179). End-products of calcination of both magnesite and dolomite vary, in density and other physical characteristics, with the intensity and speed of calcination employed. Consequently, the kiln practice changes in processing of magnesite and dolomite whereas calcination of limestone is a less complicated, more nearly fixed procedure. Inasmuch as the dissociation reaction is reversible, that is, the liberated gas can recombine with the metallic oxides, particularly under increased pressure, the processing plant must be so designed as to draw off the carbon dioxide gas as soon as it is liberated.

Two general types of kilns are commonly used in California, the vertical or shaft type and the rotary. Stone to be calcined in the vertical kiln, the type commonly found in sugar refineries, must hold its lump shape during calcination to allow circulation of the hot gases in the kiln. Most crystalline carbonate rocks, particularly the medium and coarsely crystalline varieties, cannot be used in this type of kiln. No such requirement applies to rotary kilns, but the fuel consumption is greater. Limestones and magnesian limestones that yield as little stony residue as possible after calcination are the most desirable for burning to lime, but rock containing nodules or small masses of silica, or silicate aggregates that can be readily screened out of the calcined material, has been utilized when available at lower cost.

Because of its affinity for water and for carbon dioxide, and because heat is given off during hydration and carbonatization, the kiln-discharge product (quicklime) is hard to handle. In California the market for quicklime is small and most lime is sold in hydrated (slaked) form (chiefly calcium hydroxide or calcium and magnesium hydroxides). Hydrated lime is much more stable under atmospheric conditions than quicklime and does not require special processing and handling equipment. Quicklime is commonly hydrated, after crushing to minus 1-inch size and screening out impurities, in shallow, closed pans by introduction of water. Water is added, the pan is rotated and the bottom is continuously scraped until evolution of steam ceases and the contents become light and dry. Ordinarily, about 18 pounds of water must be added to 56 pounds of high-calcium lime to make hydrated lime of the proper consistency (Bowles, 1952, p. 38). Over-slaking leaves the lime wet and sticky.

High-calcium lime slakes much faster and liberates more heat than lime containing considerable magnesite. It also hydrates more completely than magnesian (dolomitic) lime. Under simple procedures, dolomitic lime hydrates to a mixture of calcium hydroxide and magnesium oxide with little or no magnesium hydroxide. Such material behaves erratically when used in mortars and plasters. Conversely, dolomitic lime, when treated in an autoclave (pressurized chamber) under considerable pressure, hydrates evenly, has special advantages of workability and appearance over high-calcium lime and is an important building material. The design of calcining and hydrating equipment varies considerably and the processes are carried out under carefully controlled conditions. In general, no single type or design of hydrator is suitable for making all kinds of lime (Bowles, 1952, p. 38), so that a complete installation for production of all the various kinds of lime is complex and expensive.

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CHAPTER 4

MARKETING AND UTILIZATION OF CARBONATE ROCKS IN CALIFORNIA

By Oliver E. Bowen and Clifton H. Gray, Jr.

General Considerations

Limestone is one of a select few raw materials that are absolutely necessary to modern industry and our present form of civilization.* Nearly all industrial processes are dependent on critical chemical reactions in which raw materials are one or more of the necessary reacting substances. Foremost, perhaps, among these critical reactions are those of the acid-base type, wherein acidic and caustic or basic materials either react to form the product of the process or take part in side reactions that free the product for further processing. Hardly less important are the reactions that take place in the presence of heat between limestone and siliceous materials to yield portland cement and the dissociation of limestone and other carbonate rocks to yield one or more metallic oxides and carbon dioxide gas. As limestone is a fundamental caustic or basic raw material that occurs widely distributed and is available at relatively low cost; it is widely used.

Limestone occurs in nature in many degrees of purity. Calcium is the principal metallic alkaline element that gives limestone the characteristics of a fundamental material. Magnesium is another metallic alkaline element present in limestones and dolomites. For some uses, it is a fundamental and important constituent; for others, it is a harmful impurity. Aluminous, siliceous, and iron-bearing impurities may be critically deleterious in some chemical processes but beneficial in manufacture of portland cement.

Transportation and Mining Costs

The carbonate rocks are low-priced raw materials, and most products made from them are relatively low-priced. Consequently, they must be produced as near marketing centers or manufacturing plant as possible. Most of the active limestone and dolomite deposits in California lie within 150 miles of the principal consuming centers. California deposits on or close to tidewater are, however, very few; and most tidewater-located carbonate rock consuming industries are supplied from the interior of the state. From these supply points, rail freight costs \$2.50 to \$3 per ton (see table 2), and truck haulage is \$5 to \$6 per ton—an average of 2 to 4 cents per ton mile by rail or 4 to 7 cents per ton mile by truck. Inasmuch as rock can be moved by

water for as little as 1 or 2 mills per ton mile, there is considerable incentive to import limestone from Canada or Mexico. Import duties are on the order of 25 cents per ton. A schedule of rail freight rates as of September 1966 from various producing localities into the principal marketing centers of Los Angeles and San Francisco appears in table 2.

Because of unfavorable rail freight rates, distance from railroads, water supply, and poor operating conditions at some southeastern California desert deposits, both limestone and dolomite are supplied to some extent to the southern California market from Apex or Henderson, Nevada. Much of this imported Nevada stone is a nondecrepitating variety of limestone used by sugar refineries and intermittently by some steel mills. These users require a rock that will retain its lump shape during conversion to lime (or magnesian lime). Although numerous deposits found in the desert counties of southeastern California have these characteristics, very little was produced during 1973 for the reasons previously mentioned.

Costs of quarrying limestone and moving it into the processing plant are as low as 40 to 80 cents per ton in very large volume operations, such as those supporting a major cement plant. Costs in small operations may run up to several dollars per ton. Underground mining generally costs upward from 75 cents per ton of rock delivered to the mill.

Nearly all of the limestone deposits that have the economic potential to ultimately supply the San Diego marketing area consist of medium to coarsely crystalline varieties, which decrepitate to a considerable degree under calcination. One extensive district of nondecrepitating Cretaceous limestone exists close to tidewater south of Punta Banda, Baja California, within 100 miles of the Port of San Diego. This may ultimately become a source of supply for southern California because of the very low water freight involved. It currently supplies the Ensenada plant of Cementos Mexicanos in Baja California.

A few large limestone operations in California remain active even though remote from conventional marketing centers, because of a special need. For example, quarries of Stauffer Chemical Company in the Argus Range of Inyo County are more than 200 miles by truck from Los Angeles, but the need for limestone

*The two following paragraphs have been abstracted with the consent of the author, Ira C. Bechtold, consulting chemical engineer, from a private report, because they are particularly well suited to introduce this chapter.

Table 2. Railroad freight rates for limestone and dolomite

ITEM	FROM	TO	RATE					
			Open Cars			Closed or Covered Cars		
			¢ per 100 lbs.	\$ per sh. ton	Lbs. min. wt.	¢ per 100 lbs.	\$ per sh. ton	Lbs. min. wt.
Limestone (or dolomite) crude, crushed or ground	Henderson, Nevada	Los Angeles	20	4.00	80,000	21	4.20	80,000
"	Arrowlime or Apex, Nevada	Los Angeles	19	3.80	Note 1	20	4.00	Note 1
"	Sloan, Nev.	Los Angeles	22	4.40	40,000	26	5.20	40,000
"	Inca	Los Angeles	20	4.00	80,000	21	4.20	80,000
"	Cushenbury	Los Angeles	19	3.80	Note 1	20	4.00	Note 1
"	Victorville	Los Angeles	25.1	5.02	100,000	26.1	5.22	100,000
"	Calton	Los Angeles	11.5	2.30	40,000	12.5	2.50	40,000
"	Lone Pine	Los Angeles	11	2.20	(a) 100,000	11	2.20	(a) 100,000
"	Lone Pine	Saugus	10.5	2.10	Note 1	10.5	2.10	Note 1
"	Lone Pine	Saugus	11	2.20	40,000	11	2.10	40,000
"	Lone Pine	Saugus	8.5	1.70	80,000	9.5	1.90	80,000
"	Lone Pine	Saugus	8	1.60	Note 1	8	1.60	Note 1
"	Lone Pine	Saugus	18	3.60	100,000	19	3.80	100,000
"	Lone Pine	Saugus	17	3.40	100,000	18	3.60	123,000
"	Lone Pine	Newhall	19	3.80	100,000	20	4.00	100,000
"	Lone Pine	San Fernando } Van Nuys }	18	3.60	120,000	19	3.80	123,000
"	Lone Pine	Burbank	19.5	3.90	100,000	20.5	4.00	100,000
"	Lone Pine	Pasadena	18.5	3.70	120,000	19.5	3.90	120,000
"	Lone Pine	Alhambra						
"	Lone Pine	El Monte						
"	Lone Pine	Most Los Angeles area points *	20	4.00	100,000	21	4.20	100,000
"	Lone Pine	Most Los Angeles area points *	19	3.80	120,000	20	4.00	120,000

"	Lone Pine	Most Orange County points ••	20	4.00	100,000	21	4.20	100,000
"	Lone Pine	San Diego	19	3.80	120,000	20	4.00	120,000
"	Dolomite or Keeler	West Los Angeles	29	5.80	100,000	33	6.60	100,000
"	Dolomite or Keeler	Pasadena	22	4.40	100,000	26	5.20	100,000
"	Dolomite or Keeler	San Bernardino	25	5.00	100,000	26	5.20	100,000
"	Dolomite or Keeler	Fullerton Anaheim }	26	5.20	100,000	29	5.80	100,000
"	Dolomite or Keeler	Santa Ana	26	5.20	100,000	27	5.40	100,000
"	Dolomite or Keeler	San Diego	32	6.40	80,000	36	7.20	80,000
"	Dolomite or Keeler	Alhambra San Gabriel				26	5.20	100,000
Lime, common	Sloan, Nevada	Los Angeles				39.5	7.90	30,000
"	Henderson, Nevada	Los Angeles				37.5	7.50	40,000
"	Arrowlime, Nevada	Los Angeles				35.5	7.10	60,000
"	Cushenbury	Los Angeles				31.5	6.50	80,000
"	Victorville	Los Angeles				29	5.80	(b) 40,000
"	Colton	Los Angeles				22	4.40	(b) 60,000
Limestone (or Dolomite) crude, crushed or ground	Auburn	San Francisco or Oakland	12.5	2.50	140,000	18	3.60	(b) 80,000
"	Sonora	San Francisco or Oakland	13.5	2.70	140,000	20	4.00	(b) 60,000
"	Bullards (Shingle Springs)	San Francisco or Oakland	12.5	2.50	140,000	12	4.20	(b) 80,000
"	Diamond Springs	San Francisco or Oakland	13.5	2.70	140,000			
"	Hollister	San Francisco or Oakland	12	2.40	140,000			

Table 2. Railroad freight rates for limestone and dolomite—Continued

ITEM	FROM	TO	RATE					
			Open Cars			Closed or Covered Cars		
			¢ per 100 lbs.	\$ per sh. ton	Lbs. min. wt.	¢ per 100 lbs.	\$ per sh. ton	Lbs. min. wt.
"	Santa Cruz	San Francisco or Oakland	13	2.60	140,000			
"	Stockton	Manteca	12.5 11 10	2.50 2.20 2.00	40,000 100,000 Note 1	15.5 11 10	3.10 2.20 2.00	(a) 40,000 100,000 Note 1
"	Stockton	Tracy	12.5 11 10	2.50 2.20 2.00	40,000 100,000 Note 1	15.5 11 10	3.00 2.00 2.00	40,000 100,000 Note 1
"	Stockton	Mendota	20 (a) 16.5	4.00 3.30	40,000 Note 1	22 20 19 (a) 16.5	4.40 4.00 3.80 3.30	40,000 60,000 100,000 Note 1
"	Placerville	Manteca				24.5 (b) 32.5	4.90 6.50	80,000 60,000
"	Placerville	Hamilton				28.5 (b) 38.5	5.70 7.70	80,000 80,000
"	Eureka	Redding				49.5 (b) 67	9.90 13.20	60,000 80,000
"	Eureka	Ukiah				30.5 (b) 40.5	6.10 8.20	60,000 80,000
"	Eureka	Hamilton				46.5 (b) 62.5	9.30 12.50	60,000 80,000
"	San Miguel	Spreckels	10.5	2.10	100,000	10.5	2.10	100,000
"	San Miguel	Salinas	12	2.40	40,000	12	2.40	40,000
"	San Miguel	Alvarado	16	3.20	100,000	19.5	3.90	100,000
"	San Miguel	Tracy	18.5	3.70	100,000	20.5	4.10	100,000
"	San Miguel	Manteca	18.5	3.70	100,000	20.5	4.10	100,000
"	San Miguel	Betteravia	11 10.5	2.20 2.10	80,000 100,000	12 10.5	2.40 2.10	80,000 100,000
Lime, hydrated	Eureka	Redding				86	17.20	30,000
"	Eureka	Hamilton				81	16.20	30,000

"	Eureka	Ukiah	52.5	10.50	30,000
"	Placerville	Hamilton	49.5	9.90	30,000
"	Placerville	Manteca	41.5	8.30	30,000
"	Sacramento	Redding	39.5	7.90	30,000
			37.5	7.50	60,000
"	Sacramento	Hamilton	31.6	6.30	30,000
"	Sacramento	Woodland	25.5	5.10	30,000
"	Sacramento	Placerville	34.5	6.90	30,000
"	Sacramento	Clarksburg	23.5	4.70	30,000
"	Stockton	Manteca	23.5	4.70	30,000
"	Stockton	Tracy	21.5	4.30	30,000
			18.5	3.70	Note 2
"	Stockton	Mendota	44.5	8.90	30,000
			35.5	7.10	80,000
"	Oakland	Tracy	36.5	7.30	30,000
"	Oakland	Mendota	50.5	10.10	30,000
"	Oakland	Salinas	50.5	10.10	30,000

Railroad freight rates on crude, crushed or ground limestone and dolomite and hydrated lime from points nearest the principal producing localities to some common receiving points in California. The rates are approximately those in effect in January 1967. The rates listed are for carload lots in cents per 100 lbs. and dollars per short ton. When the carload lots have a minimum required weight and when different minimum required weights have been established for open and closed or covered cars this is so designated. The freight rates have been derived largely from Interstate Commerce Commission Freight Tariff 27A and D, plus supplements, distributed by the Pacific Southcoast Freight Bureau through the Courtesy of W. H. Crutchfield and Associates of the Atchison, Topeka and Santa Fe Railway Company at Los Angeles; W. Wreckerley and associates of the Southern Pacific Company at San Francisco; Fred N. Woods III and Jack Bravo of California Rock and Gravel Company; Woodrow Slade of Owens-Illinois Glass Company; and Donald Gustafson of Premier Resources, Inc.

Note 1

Minimum weight of marked capacity of car used, except when loaded as full as loading conditions permit actual weight will apply, but not less than 120,000 pounds.

(a) Except if car is loaded to weight carrying capacity, actual weight will apply, but not less than 80,000 pounds.

(b) Not subject to follow lot car.

Note 2 Applies only in bulk in covered hopper cars which carriers are not obligated to furnish subject to minimum weight of marked capacity of car used, except when loaded to full space capacity, actual weight will apply, but in no case less than 140,000 pounds.

* *Includes:* Culver City, West Hollywood, Hollywood, Beverly Hills, West Los Angeles, Santa Monica, Venice, Inglewood, El Segundo, Gardena, Torrance, Compton, Dominguez, Lynwood, Paramount, Wilmington, Los Angeles Harbor, Long Beach, Bassett, Beldwin Park, Covina, San Dimas, La Verne, Pomona, Walnut, Whittier, La Habra, Buena Park.

** *Includes:* Fullerton, Anaheim, Orange, Santa Ana, Tustin, Dyer.

at the chemical plant at Westend on Searles Lake makes the operation feasible. Likewise, quarries of Eaton and Smith at Lime Mountain, San Luis Obispo County, supply sugar refineries in Salinas Valley. Both of these localities are distant from the San Francisco and Los Angeles marketing complexes. In addition, quite a few smaller, intermittent operations are based on special local marketing conditions rather than adjacency to large marketing centers. At present almost all of the limestone and dolomite produced in California is consumed in this state, although some specially processed materials, such as whiting, are shipped as far as Canada. Special purpose architectural stone, in limited amounts, is shipped throughout the United States.

Prices

Prices on the open market for limestone and dolomite vary widely depending upon the amount of material sold, the degree of processing necessary, the chemical and physical specifications the rock must meet, the demand for the for the particular variety being offered, and the competition among producers. Consumers that operate on a large scale generally can negotiate lower prices than small buyers. During 1973, sellers on the open market received \$3 to \$6.25 per short ton, f.o.b. shipping point, for limestone having a calcium carbonate content of 96 to 98 percent and crudely sized to dimensions such as 2x4 or 4x6 inches. Ground products sold at \$9 to \$12 per ton and very finely ground products, such as air-separated material, in micron sizes, sold at prices ranging from \$15 to \$25 per ton.

Rock sold for use as road base, concrete aggregate and the like occasionally sold as low as \$1 per ton although much was sold in the range of \$1.50 to \$2. Packaged items such as poultry grit and roofing granules sold for \$9 to \$15 per ton. The highest prices obtained in recent years for crudely sized limestone have been for limestone used in glass manufacture where a very low iron content is necessary, in some sugar refineries where fine-grained, tenacious varieties are specified, and in making white fillers where uniform white color as well as high purity are required. Packaging commonly costs 3 or 4 dollars per ton.

Much of the carbonate rock in California, including most of the dolomite, is captive tonnage; that is, the quarrying and processing is done by the manufacturer who is converting the raw material into a new product. The value of the crude rock to such an operator is chiefly the cost of mining and processing plus the depletion and amortization of the deposit and plant. Consequently, there may be a considerable discrepancy between the value reported to statistics-gathering agencies and equivalent materials sold on the open market. The only dolomite sold on the open market goes into products such as terrazzo chips, roofing granules, poultry grit and road base, where prices received are roughly equivalent to those paid for limestone.

Table 3. Open market prices for lime and limestone in California in 1971.

<i>Use Category</i>	<i>Price Range (per ton)</i>
1. Lime for chemical and refractory use	\$18.60-23.00
2. By-product, impure lime for agricultural use, road-base stabilization, etc.	3.00- 5.00
3. Roofing granules	4.00-15.00
4. Terrazzo chips	20.00-25.00
5. Rough building stone	9.40-37.35
6. Oyster shells (agricultural)	9.00-11.00
7. Flux in refining of metals	2.50- 4.00
8. Refractory dolomite	5.00- 6.00
9. Sugar refining	3.00- 4.50
10. Glass manufacturing	4.20- 5.40
11. Paper manufacturing	5.00- 5.70
12. Whiting	4.30-20.00
13. Poultry grit	3.10-10.50
14. Fertilizer filler	5.85-10.00
15. Stucco and plaster sand	6.20-10.00
16. Mineral food	5.00- 6.00

Uses, Consumption and Specifications

Use of limestone in a great many chemical processes has been steadily rising with California's population. Although use of limestone may be reduced for some purposes, such as in sugar refining, by changing technology, the trend is currently upward at the rate of 10 or 12 percent per year.

Table 4. Some of the many uses for limestone and dolomite.

A. Limestone

Chemical Industries

- Source of calcium
- Source of carbon dioxide

Construction Industries

- Chief raw material used to make portland cement
- Chief raw material used to make lime
- Aggregate for concrete, especially white aggregate
- Aggregate for road base, railroad ballast, and asphalt paving
- Riprap
- White pigment and extender in paint
- Filler in asphalt-base roofing, asphalt tile and linoleum
- Roofing granules
- Terrazzo chips
- Ornamental garden rock

Agriculture

- Additive in prepared livestock feed
- Neutralizer of acid soils
- Plant food
- Coagulant or flocculant in conditioning clay soils

Table 4. Some of the many uses for limestone and dolomite—Continued.

Mining and Metallurgy

- Flux in ferrous and non-ferrous metallurgy
- Flux in manufacture of ceramic products
- Scavenger of sulfur and phosphorus in steel manufacturing
- Dusting in coal mines to reduce fire hazard
- Whitening of mine walls

Miscellaneous Industries

- Manufacture of glass
- Refining of sugar

B. Dolomite and Magnesien Limestone

Magnesium Refractories and Chemicals

- Dead-burned dolomite
- Periclase brick
- Chrome-magnesia brick
- Magnesium oxide
- Hydrated magnesia
- Magnesia pharmaceuticals
- Magnesium chemicals

Construction Industries

- Aggregate, railroad ballast, road metal
- Roofing granules and terrazzo chips
- Magnesien lime for plaster

Agriculture

- Soil conditioner
- Animal and plant food
- Ingredient in insecticides and fungicides

Miscellaneous Uses

- Manufacture of glass
- Source of carbon dioxide
- Source of metallic magnesium

C. High Calcium Lime

Chemical Industries

- Source of calcium in the manufacture of other chemicals:
 - Caustics and alkalies
 - Calcium carbide, calcium bisulfite, calcium cyanamide, etc.
- Vehicle in base exchange in manufacture of such products as magnesium salts
- Neutralizer of acids
- Catalytic agent in numerous processes
- Dehydration of such materials as alcohols and petroleum products
- Precipitating and coagulating agent

- Hydrolizing agent in glue, rubber and paper-pulp manufacturing
- Saponification of fats and oils in manufacture of calcium soaps
- Oxidizing and reducing agent in various processes
- Gas absorbent
- Solvent, as in tanning of hides and smelting of metals

Construction Industries

An ingredient in:

- Lime mortar
- Plaster
- Stucco
- Paint pigment
- Sand-lime and silica brick
- Rock wool

Filler in:

- Asphalt-base roofing
- Asphalt tile
- Linoleum

Additive in concrete, increasing:

- Waterproofing characteristics
- Workability (plasticity)

Agriculture

- Plant food
- Neutralizer of acid soils
- Coagulant or flocculant in clay soils
- Ingredient in insecticides and fungicides
- Filler in insecticides and fertilizers
- Animal food
- Animal sanitation
- Food preserving

Mining and Metallurgy

- Flux in ferrous or non-ferrous metal reduction
- Flux in manufacture of ceramic products
- Scavenger of sulfur and phosphorus in steel manufacture
- Acid neutralizer in ore dressing
- Dusting in coal mines to reduce fire hazard
- Whitening of mine walls

Miscellaneous Industries

- Manufacture of soap
- Manufacture of glue
- Manufacture of bleaching powder
- Manufacture of varnish and paint
- Manufacture of rock wool
- Manufacture of glass
- Manufacture of paper
- Manufacture of refractories
- Refining of sugar
- As disinfectant

Table 5. Estimated consumption of limestone in California by principal uses. Includes calcite marble and oyster shells; commercial and noncommercial rock; plus limestone imported into California from Nevada, Texas, and other states and foreign countries.

Use	1970		1969		1965	
	Quantity in short tons	Value	Quantity in short tons	Value	Quantity in short tons	Value
1. Portland cement	13,480,470	\$13,583,976	13,718,625	\$13,899,318	12,400,000	\$12,000,000
2. Road base	1,160,948	1,235,101	1,458,990	1,554,583	—	—
3. Concrete aggregate	508,247	440,310	701,209	773,742	946,000	1,206,000
4. Flux stone	665,000	640,000	678,000	761,000	650,000	670,000
5. Sugar refining	314,200	904,833	327,360	950,034	375,000	1,055,000
6. White fillers	330,442	2,784,726	201,128	2,001,700	134,000	1,639,000
7. High-calcium lime	240,300	870,349	376,830	1,217,737	500,000	1,414,000
8. Glass manufacturing	230,315	1,097,604	276,094	978,412	210,000	1,007,000
9. Poultry grit	138,100	848,052	102,622	641,733	89,000	797,000
10. Roofing granules	110,000	610,000	33,901	195,951	90,000	604,000
11. Miscellaneous aggregate	54,372	101,902	102,185	476,746	—	—
12. Building stone	51,032	100,000	64,432	426,077	51,000	318,000
13. Macadam aggregate	30,892	76,955	63,027	157,558	—	—
14. Mine dusting	24,732	110,917	—	—	—	—
15. Riprap	22,519	41,260	38,347	122,188	—	—
16. Terrazzo chips	69,125	199,266	70,946	244,791	—	—
17. Agricultural limestone (soil conditioners, fertilizer filler, insecticides, etc.)	53,000	435,210	53,207	187,691	156,000	1,244,000
18. Miscellaneous, not aggregates	189,217	1,071,046	253,148	1,214,071	—	—
Totals	17,672,911	\$25,151,507	18,520,051	\$25,803,332	15,595,000	\$21,948,000

Table 6. Estimated consumption of dolomite in California by principal uses. Includes dolomite, magnesian limestone, dolomite marble (rough) and dolomite marble dimension stone obtained both in and out of the state, both commercial and noncommercial.

Use	1970		1969		1965	
	Quantity in short tons	Value	Quantity in short tons	Value	Quantity in short tons	Value
1. Magnesian lime	362,199	\$2,710,922	506,376	\$1,396,737	515,000	\$1,252,000
2. Concrete aggregate and road base	50,212	109,033	22,127	77,245	90,000	222,000
3. Dead burned dolomite	43,073	75,360	12,043	60,172	12,000	73,000
4. Magnesium chemicals	27,468	130,473	—	—	40,000	155,000
5. Terrazzo chips	23,363	446,160	16,154	252,525	64,000	865,000
6. Glass manufacturing	21,503	88,347	—	—	12,000	73,000
7. Soil conditioners	12,783	31,958	47,614	95,009	—	—
8. Refractory stone	11,464	57,320	11,812	59,060	—	—
9. White surfacing	10,608	31,739	14,128	25,007	—	—
10. Poultry grit	8,126	24,378	—	—	—	—
11. Roofing granules	3,208	42,987	4,256	40,655	—	—
12. Magnesium metal	1,403	18,800	—	—	—	—
13. Steel flux	943	2,358	1,761	17,223	32,000	88,000
14. Building stone	469	3,865	3,834	73,886	—	—
15. Riprap	—	—	15,494	32,235	—	—
16. Miscellaneous (mainly aggregates of unspecified type)	31,514	52,807	5,523	73,469	16,000	93,000
Totals	608,336 +	\$3,826,507 +	664,122	\$2,203,223	781,000	\$2,821,000

Table 7. Specifications for limestone and dolomite and lime for the principal consuming industries*

Use	Chemical Requirements	Physical Requirements
Limestone for portland cement	Magnesium oxide (MgO) not more than 3%, preferably not more than 2%. Total alkalies not more than 0.5%. Minimum calcium carbonate (CaCO_3) content varies from plant to plant depending upon availability of other raw materials, but generally is more than 82%.	Some manufacturers prefer limestone that does not deprecitate during calcining, i.e., that will hold its lump shape throughout calcination.
Limestone for lime (high calcium)	Calcium carbonate (CaCO_3) content not less than 97%, preferably 98% or more.	Some manufacturers prefer rock that does not deprecitate during calcining.
Magnesian limestone for lime (magnesian)	Magnesium oxide (MgO) content should fall between the limits of 10 and 15%, preferably 11–12%.	Some manufacturers specify rock that will not deprecitate when heated.
Limestone and magnesian limestone for steel flux (blast furnaces)	Silica (SiO_2) less than 5%, less than 2% preferred. Alumina (Al_2O_3) less than 2%. Magnesia (MgO) less than 4% to less than .15% at various plants. Phosphorus pentoxide (P_2O_5) not more than a trace, i.e., .005 to .006.	Some manufacturers specify rock that holds its lump form until consumed in the melt.
Limestone for steel flux (open hearth)	Calcium carbonate content preferably not less than 96%, lower grades occasionally accepted. Phosphorus must not exceed trace amounts.	
Dolomite for refractories	Magnesium oxide (MgO) not less than 18%. Silica (SiO_2), ferric oxide (Fe_2O_3) and alumina (Al_2O_3) not to exceed 1% each, but lower grades sometimes accepted.	Some manufacturers require rock that will not leave a scum when dissolved in acid.
Limestone for general chemical use	Calcium carbonate content should exceed 98%. Preferred rock runs more than 99% CaCO_3 . Limestone as low as 97% CaCO_3 is sometimes accepted.	
Limestone for beet-sugar manufacturers	Silica (SiO_2) not more than 1%. Magnesia not more than 4%. At some plants ferric oxide (Fe_2O_3) must not exceed 0.5%.	To be acceptable at most California plants limestone must retain its lump form during calcination (burning).
Agricultural limestone	In general the higher the lime (CaO) content the better the price. Rock containing less than 85% CaCO_3 is seldom accepted.	Other factors being equal, a soft friable rock is more acceptable because it is cheaper to process.
Agricultural dolomite	The price received is dependent mainly on the calcium-magnesium carbonate content, rocks being seldom accepted if they contain less than 85% of carbonate minerals.	Same as agricultural limestone.
Limestone and dolomite for glass	Ferric oxide (Fe_2O_3) not more than 0.05%, preferably not more than 0.02% for colorless glass, rock having up to 0.1% Fe_2O_3 is sometimes accepted for colored container glass. Calcium carbonate (CaCO_3) should exceed 98% in case of limestone, or 98% calcium-magnesium carbonate in case of dolomite. Amounts of silica, alumina, magnesia etc., must not vary from shipment to shipment.	Some plants specify rock having a low deprecipitation factor.
Limestone for calcium carbide and calcium cyanimide	Calcium carbonate (CaCO_3) content must exceed 97% and should exceed 98%. Magnesium oxide (MgO) should be less than 0.5%; alumina and ferric oxides (together) less than 0.5%; silica (SiO_2) less than 1.2; and phosphorus less than 0.01%. Sulfur must not be present in greater than trace amounts.	Rock must retain its lump form during calcination.
Limestone for paint and filler	In general the calcium carbonate content should exceed 96% but magnesian limestones containing as much as 8% magnesium oxide occasionally are tolerated—the MgCO_3 content generally is 1%. Other maxima are: Fe_2O_3 —0.25%, SiO_2 —2.0% and SO_2 —0.1%.	Rock which breaks down into rhombic particles is preferred in some plants. The main controlling characteristic is the degree of whiteness shown by the processed material.
Limestone and dolomite for concrete aggregate, ballast, road metal, road base	Concrete aggregate should be low in alkalies and free from surface organic matter. Presence of opaline silica is highly undesirable in concrete aggregate. Other aggregate suitability is based chiefly on durability, particularly toughness.	Must be clean, strong, durable, and of low porosity.
Quicklime for pulp and paper manufacturers	Calcium carbonate (CaCO_3) contents must be more than 96% for most manufacturers.	Must be thoroughly hydrated, fine grained and free of grit.

Lime for soft rubber goods	Magnesian lime is generally used. Must be free from carbonates and should contain less than 3% of total impurities other than carbon dioxide or magnesium oxide. In vulcanization such lime must also be free of manganese, copper, and calcium oxides.	
Lime for lubricants (greases)	Calcium oxide not less than 72.6%, magnesium oxide not more than 1%, maximum silica plus iron plus alumina, 1.5%, maximum carbon dioxide (at point of manufacture) 1%.	Must be completely hydrated and free of grit.
Lime for textile dyeing	Calcium carbonate (CaCO_3) not less than 94%, alumina-iron not more than 2%, silica not more than 2.5% and magnesia not more than 3%.	
Varnish	Must be very low in iron and magnesium oxide.	Must be very fine grained and very white.

* This table indicates such chemical and physical requirements as have been standardized by the various consuming industries.

History of Utilization of Carbonate Rocks in California

The use of lime-bearing materials dates back to the building of the Spanish missions, where whitewash and lime mortars were used widely in small quantities. Abalone shells collected on the beaches probably were the first raw material burned into lime. Accumulations of fossils shells were found and used later, and finally the crystalline limestones were discovered and used locally. Not until the gold rush days of the middle 1850's did lime become important in the construction industry, but from then on, until the early 1900's, lime kilns sprang up all over California. The rise in demand for lime was directly related to the disastrous fires that repeatedly swept through towns composed of wooden frame buildings. Field stone or brick buildings laid up in lime mortar or mud and shuttered in steel became the standard type of construction throughout the gold country; many of these are still in use. A large quantity of lime was imported from Europe to supply the demand for masonry mortar during the gold rush.

The lime-burning business probably had its heyday between 1880 and 1900—in relation to its importance to the economy of that time if not in actual tonnage produced. Vast banks of lime kilns were constructed in the Santa Cruz Mountains, Santa Lucia Range, Sierra Nevada foothills, Tehachapi Mountains, and southwestern San Bernardino County. Many of these lime companies were as significant for their day as the portland cement companies now are—in relation to the rest of the economy.

Although portland cement was invented in England as early as 1825, it was not used to any great extent in California until the late 1850's and 1860's. The first cement used here was imported from Europe. Even then it did not greatly supplant lime mortars, nor did concrete become serious competition to masonry construction until about the turn of the century. Cement manufacturing in California dates back to 1860 when a hydraulic cement (a type manufactured at considerably lower temperature than portland cement) was placed on the San Francisco market. This was made at Benicia, Solano County, probably from scattered deposits of limy concretions, seashells and caliche plus clay. The first cement approaching the true portland type was made at Santa Cruz about 1877, from crystalline limestone and clay. Another early plant that produced a portland-type cement was built on the Jamul Ranch, San Diego County, in 1891. Since the early 1900's, cement plants have been the largest consumers of limestone in California, but numerous other industrial uses of limestone are equally important to the economy of California even though the quantity of material they consume is smaller.

Three other major limestone-consuming industries have figured prominently in the marketing of limestone in California for more than 75 years—sugar refining, steel manufacturing and glass manufacturing. Perhaps the steadiest consumer among these has been the beet sugar refining industry, which started in a small way as early as 1856, continued intermittently until 1889 and has been a steady consumer ever since. Present consumption exceeds 280,000 tons annually in

California. However, inasmuch as the newer plants are being designed to recycle pond limes, future use of limestone in sugar beet processing is expected to decline.

Steel making in California dates back to gold rush times and the advent of such foundries as the Joshua Hendy Iron Works. Limestone, however, was not used in any great quantity until the erection of the steel mill at Clipper Gap, Placer County, in 1880. Steel foundries and casting companies have been fairly large consumers of limestone and lime ever since. Erection of the Kaiser steel mill at Fontana, San Bernardino County, in 1942 resulted in a major increase in steel flux consumption in California. For a time, much of the fluxstone was imported from Nevada; but this has been greatly reduced. Current California consumption is on the order of 500,000 tons per year.

Glass-making in California began in a small way as early as 1858 but was intermittent until about the turn of the century. Some early day factories used lime instead of the limestone now consumed. Notable periods of expansion have been the 1920's and the period since World War II. California's first plate glass plant was opened at Lathrop (near Stockton) by Libby-Owens-Ford in 1964. Plans for an additional plant at Fresno were progressing in 1966. Approximately 200,000 tons of limestone is consumed each year by California glass manufacturers.

Dolomite was probably first used in California as a building stone. Dolomite dressed stone and field stone was used exclusively in the Sonora district of the Mother Lode in the 1850's and 1960's, and dolomite marble dimension stone was produced in Inyo County as early as 1888. Dolomite production was small and intermittent until 1942, basic flux for steel making being the principal product. In 1942, the Henry J. Kaiser interests initiated the use of dolomite as the principal raw material for use in magnesia refractories. During the decade following, other California producers of magnesia altered their processes to utilize dolomite. The refractories industry now is by far the largest user of California dolomite. Prior to the advent of the use of dolomite, magnesia and other magnesium chemicals had been made from interaction of lime with sea water or from relatively small deposits of magnesite. Interaction of calcined dolomite with sea water results in a substantially larger yield of magnesia than lime plus sea water.

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CHAPTER 5

DEPOSITS PARTICULARLY PROMISING FOR NEAR-FUTURE DEVELOPMENT

By Oliver E. Bowen and Clifton H. Gray, Jr.

Development and utilization of hitherto unused deposits of California limestone and dolomite on a major scale will depend primarily upon: (1) patterns of population growth; (2) advances in manufacturing technology; (3) construction of new transportation arteries (mainly highways); (4) placement of trunk utility lines, especially water, gas, and electric power; and (5) the degree of restriction that will be placed upon new and existing quarries and manufacturing plants through urban development. Expansion and centralization of populations inevitably result in intense competition for land among conflicting interests, particularly among the residential property interests, industrial property interests, fundamental raw material suppliers (i.e. rock, sand and gravel) and numerous recreational interests. Some counties and municipalities are pioneering in the field of land use planning with respect to utilization of mineral resources. Statewide studies of these problems are also underway.

Carbonate rock deposits and districts believed to be of notable near-future economic importance are briefly summarized below. These will be described at greater length as the results of the other parts of a statewide investigation are published. The parenthetical notation at the end of each summary identifies the part of the investigation involved and the specific deposits described in some detail therein. No particular order of importance or specified time of probable development is implied in the following discussion.

Southern California

COYOTE-FISH CREEK MOUNTAINS

Steady growth of the San Diego marketing area ultimately should be sufficient incentive for development of the extensive deposits of blue-gray crystalline limestone in the Coyote and Fish Creek Mountains of west central Imperial County, notably those in the vicinity of Carrizo Mountain. During 1966, Texas Industries acquired and explored a large deposit at Carrizo Mountain. Reserves run into the hundreds of millions of tons. No other deposits of large size and high quality that might serve the San Diego area exist within the boundaries of the United States nearer than the northern San Bernardino Mountains or the Santa Rosa-San Jacinto Mountains complex. Because of the very low-cost water freight, it is, of course, possible to import limestone or dolomite into the Port of San Diego from Mexico or Canada at prices competitive with domestic rock. Extensive deposits of Cretaceous

limestone exist on the west coast of Baja California within 100 miles of San Diego. (Coyote Mountains, Jumbo, Mountain Spring and Waters; Transverse and Peninsular Ranges Province VII)

BACK CANYON

A district containing notable reserves of apparently high-grade, coarsely crystalline white and blue gray limestone exists within 15 miles of the producing Tehachapi-Monolith district of Kern County at the headwaters of Back Canyon in the upper Caliente Creek drainage basin. These deposits are 12 to 18 miles from State Route 58 and the rail lines of the Tehachapi Pass and Owens Valley routes. Construction of one or more of the proposed new roads to serve this vicinity would put these deposits in a good competitive position; lack of good access roads has delayed their development. (Monarch Lime Company, Loraine, Ritter Ranch and Rudnick Estate; Province IV)

SAN BERNARDINO MOUNTAINS

Very large reserves of limestone and some dolomite are distributed through the northern San Bernardino Mountains centering in the Cushenbury Canyon vicinity. Some of these have already been placed in operation by Kaiser Cement and Gypsum Company, Chas. Pfizer & Co., and several smaller concerns. Presence of a rail line to Cushenbury Canyon has increased the desirability of these deposits, although some are situated high in the mountains and would have to be served by truck. Much of the rock in this district is white or nearly so and suitable for many specialty products as well as for cement and general chemical use. (Blackhawk Canyon, Carriere, Cushenbury Canyon, Grapevine Creek, Kaiser Cement and Gypsum Corporation, Chas. Pfizer & Co., Inc., Rattlesnake Gulch, Rose Mine area, Tip Top Mountain, Twin Row, Sentinel, Golden Eagle Placer, White Mountain, Hesperia, Bowen Ranch, Blackhawk Mountain, Terrace Springs, White Rock, and Marmo-Diamante; Province VII)

KEELER AREA

Very extensive reserves of white, high purity dolomite exist near the rail line in the Keeler-Lone Pine district of Inyo County in both the Hidden Valley Dolomite and Anvil Springs Formation of Ordovician to Silurian age. High-purity white and blue-gray limestone deposits are also present in the nearby Lee Flat and Darwin districts to the east and southeast of Keel-

er, mostly in the Mississippian Bullion Member of the Monte Cristo Limestone. Premier Resources, Inc. currently produces dolomite marble near Keeler. (Limestone deposits in the Lee Flat, Darwin and Talc Hills vicinities and Dolomite district east of Lone Pine; Province V)

MARBLE MOUNTAINS

A considerable variety of limestone and dolomite deposits exists in the Marble Mountains of eastern San Bernardino County within 15 miles of the railhead at Cadiz. The proposed realignment of Interstate Highway 40 and possibly the railroad as well would improve the desirability of these deposits. Substantial deposits also occur in the adjacent Bristol and Ship Mountains. The district is particularly well known for the highly colored limestones and coarser grained marbles that are in various combinations of blue, black, red, and orange. The most attractively colored limestones tend to occur in the Cambrian Cadiz Formation although some exist in other Cambrian formations as well. Extensive deposits of massive, blue-gray to nearly white limestone and dolomite are found in several unnamed metamorphosed formations of late Paleozoic age in the northwestern part of the Marble Mountains. These are suitable for cement and for general chemical use. (Chubbuck Reserve, Vaughan Marble, Marble Dolomite, Snowcap, Jack Frost, Chalmers Dolomite, Castle Dolomite, Twin Buttes, and Ship Mountains; Province VI)

LAKE HEMET VICINITY

The Whitlock deposit, located a few miles southeast of Lake Hemet in the San Jacinto Mountains of western Riverside County, is one of the few remaining undeveloped deposits less than 100 airline miles from Los Angeles or San Diego that appears to be large enough to support a modern cement plant. A limited water supply and difficulties of finding a suitable manufacturing plant site, because of urbanization or inadequate utilities, has delayed development. (Province VII)

CIMA AREA

The Striped Mountain vicinity of the Mescal Range in northeastern San Bernardino County lies within 12 miles of the Union Pacific siding at Cima and three miles east of Cima road. Immense reserves of both blue-gray and white limestone of apparently good grade are exposed over favorable quarry terrain. The Bullion Member of the Mississippian Monte Cristo Limestone, The Crystal Pass Limestone Member of the Devonian Sultan Limestone, and certain parts of the Cambrian to Devonian Goodsprings Dolomite are the most promising objectives. Large masses of fine-grained, nondecrepitating high calcium limestone are available that can be competitive with rock currently imported from Nevada. (Cima Limestone, Geer Dolomite, and Mescal Range-Clark Mountains-Ivanpah Mountains; Province VI)

MARIA MOUNTAINS

White limestone and white dolomite of apparently high purity are found in the Little Maria and Big Maria Mountains of eastern Riverside County near

Midland. Reserves are estimated to run into the hundreds of millions of tons. These carbonate rocks occur chiefly in the Maria Formation of probable Paleozoic age. Distance from markets and unfavorable rail freight rates have hindered development of these deposits although small tonnages of ornamental stone have been marketed. They are, however, within a few miles of paved roads and a branch rail line. (Blythe Cement Nos. 1-5, Bonnie Limestone, California Limestone Products, Driftstone Veneer Nos. 1-2 and Driftwood No. 2, Limestone Nos. 1-8, and Shane Nos. 1-2; Province VII)

FRAZIER PARK

In the general vicinity of Frazier Park, southwestern Kern County, coarsely crystalline white to gray, massive limestone occurs in numerous pendants in Mesozoic granitic rocks. The area has numerous deposits suitable in quality for manufacture of portland cement and for general industrial chemical use. Some doubt exists whether the reserves are large enough to attract a large cement plant. The deposits are close to a paved road and are about six miles west of U.S. Highway 99 (Interstate Route 5). Although the deposits are situated between the Los Angeles and Bakersfield marketing areas, lack of rail facilities may prove a deterrent. Thus far, roofing rock has been obtained in this area. (Lebec, Tecuya, and White Ridge; Province VII)

SAN GORGONIO PASS AND VICINITY

Several undeveloped deposits of moderate to possibly large size exist in the northern San Jacinto Mountains. These deposits contain considerable tonnages of high calcium-low iron limestone but also include intermixed dolomite and magnesian limestone. They are close to rail transportation and to Interstate 10, but their development has been hindered by problems of access across adjoining lands and opposition by residential property interests. Among the more accessible of these are the Guiberson and Sims deposits. (Others include the Blue Diamond, Chino Canyon, Eagle, Fingal, Mount Edna, Novelle, Potrero Creek, and Southern Pacific; Province VII)

SAN MARCOS PASS VICINITY

Moderately extensive deposits of fine-grained, light-colored algal limestone occur in the Eocene Sierra Blanca Limestone in the Little Pine Mountain vicinity of Santa Barbara County. These lie within ten miles of good county roads (the San Marcos Pass route) and constitute one of the few sources of industrial limestone in this part of the state. Lack of good access roads, as well as limited market opportunities, has delayed utilization of these deposits. Some are close to or within the proposed San Rafael Wilderness Area. (Sierra Blanca; Province III)

Northern California

PICO BLANCO

The only extensive high-grade limestone deposits on the Pacific Coast of the United States, exclusive of Alaska, within three miles of potential marine transportation are in Monterey County, 25 miles southeast of Monterey at Pico Blanco and vicinity. Reserves

there are on the order of a billion tons. Most of the rock in these deposits is coarsely crystalline, snow white, and of high purity, which further enhances the desirability of the deposits for many industrial purposes. However, utilization of this extremely valuable group of deposits is already threatened by urbanization and conflict of interests. (Pico Blanco; Province III)

LAKE SHASTA AREA

Various deposits in the vicinity of Lake Shasta, Shasta County, contain the only extensive reserves of fine-grained, nondecrepitating limestone available within reasonable distance of northern California markets. The only likely sources elsewhere would be from Mexican or Canadian deposits competitive because of the very low cost of water freight. The Hos-selkus Limestone and Pit Formation of Triassic age contain the most uniform rock and the rock most likely to be low in magnesium. The more extensive McCloud Limestone of Permian age locally is good but has extensive replacement masses of dolomite more or less throughout. Limestone of the Devonian Kennett Formation is generally of good quality, but few of the deposits are large and most are relatively inaccessible. (Province II)

VOLCANO AREA

Large uniform deposits of blue gray, crystalline limestone are present at Volcano, Amador County, within 12 miles of the railhead at Martells. These have been controlled for many years by the Riverside Cement Division of American Cement Corporation. They were being explored as sources of industrial limestone and for a future cement plant at Lone in 1966-67. They are particularly well situated to supply future Central Valley markets. (Volcano Limestone; Province IV)

MURPHYS-COLUMBIA-SONORA AREA

This district already supports several important producers of industrial limestone and dolomite, and other properties are already marked for near-future exploration. Reserves of both limestone and dolomite are very large. Centrally located within 125 miles of San Francisco, adjacent to the Central Valley, and well supplied with trunk utility and transportation lines—this district is attractive to new industry. Within the next few years, The Calaveras Cement Division of The Flintkote Company will activate its properties in Cataract Gulch to supply its already existing plant at San Andreas. (Childress Ranch, Columbia Ditch, Columbia Dolomite, Eastman Ranch, Hyde Ranch, Letora Ranch, Mayhall Ranch, Murphys, Musante Ranch, Port Stockton Cement, San Diego Reservoir, Skunk Gulch, Woodham Ranch deposits; Province IV)

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As a convenience to the reader, this comprehensive list of references includes those previously listed at the end of each chapter to which they specifically pertain. The number in parentheses at the end of each reference in this list indicates the number of the chapter where previously listed. Additional references of general interest and scope in the field of economics of the carbonate rocks have been added. These have no parenthetical number.

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LIMESTONE AND DOLOMITE DEPOSITS IN CALIFORNIA

This list contains the names and synonyms of all deposits of limestone and dolomite in California, as known to the authors of this bulletin. Additionally, the names of significant operators are shown, together with the principal name or names of the deposits connected with those operations.

The principal name of each deposit is followed parenthetically by applicable synonyms, then by the designation for the Carbonate Rock Province and District in which the deposit is located (see Investigation Plan and Organization section, including list of Districts, at beginning of this publication), and, finally, by the District deposit number. In some cases, a deposit is known only by the operator's name and will be represented by a single entry—"_____ Company Deposit." A few deposits, described in text but not located on plate 1, are designated by ND in place of a deposit number.

The reader is thus directed to the portion of this investigation in which the deposit is described or listed; the District designation and District deposit number enable the reader to locate the deposit on plate 1, accompanying this publication, and on the appropriate plates in subsequent publications or open file reports. Deposits are numbered from north to south within each District.

CARBONATE ROCK PROVINCES

Klamath Mountains Province, II
Coast Ranges Province, III
Sierra Nevada Province, IV
Basin Ranges Province, V
Mojave Desert Province, VI
Transverse and Peninsular Ranges Provinces, VII

Compiled by Marilyn Dayton and Lucy O'Brien

A. S. and R; III-C-1; 8
Abramson and Bode (see Oat Canyon)
Adelanto; VI-10; 2
Agricultural Lime and Compost Company (see San Francisco Bay Shell Deposits)
Alabaster Cave (see Rattlesnake Bar)
Alamo Consolidated (see Verde Antique)
Alisal; III-C-6; 6
Allen Estate (see Allen Ranch)
Allen Ranch; IV-B-2-B; 2
Allen Travertine; IV-C-7; 10
Allied Desert Products Quarry; VI-9; 33
Almaden; III-C-5; 3
Alta Lime & Brick Company Deposit; II-2; 10
Alvord Mountain; VI-5; 2
Amador Lime Rock (see Preston Reservoir Limestone)
Amargosa Travertine; V-11; 2
Amercil; VII-2; 2
Amercil Mining Company, Inc. (see Amercil)
American Cement Corporation (see Riverside Cement Company)
American Minerals Company (see Grapevine Creek)
American Sugar Beet Company (see Oro Grande Canyon)
Anchor Minerals (see Snow White)
Anchor Minerals and Chemicals, Inc. (see Pfizer, Chas., and Company, Inc., Deposits)
Anderson (see Tip Top Mountain Limestone)
Angeles Mining and Milling Company (see San Antonio Canyon Dolomite)
Angels Creek; IV-B-4-A; 10
Antelope Valley Marble (Pescado Creek); VII-1; 13
Argilla (see Matilija Canyon)
Argus Range Onyx (Death Valley Onyx); V-12; 3
Arica Mountains; VI-11; 1

Arizona Stone Company (see Blackhawk Mountain)
Arlington (Marysville—see Nelson Bar text); IV-A-2; 14
Arlington and Black Hawk (see Blackhawk Canyon)
Armstrong Canyon; IV-C-3; 2
Ash Mountain; IV-C-4; 7
Asher; II-2; 14
Atlas Rock (see White Rock Limestone Quarry)
Auburn; IV-B-1; 13
Auburn Lime Company (see Rattlesnake Bar)
Auburn Lime Products Company (see Rattlesnake Bar)
Aumeier and Rodriquez; III-C-5; 7
Badger Flat (see Mazourka Canyon, Bonanza King Formation)
Bagby; IV-B-6; 7
Baker; VI-2-C; 1
Bald Mountain; IV-B-4-A; 4
Baldy Ryan; III-B-4; 13
Barbee Ranch; III-C-1; 1
Bardin (see Hartnell Group)
Bardin Ranch III-C-1; 11
Berker Creek; II-3; 17
Berker Mountain; II-3; 15
Bernes Construction Company (see Quail Creek)
Berstow Ferruginous Dolomite; VI-5; 6
Basin Siding; VI-2-C; 3
Baughman Dolomite; VII-2; 6
Bautista Canyon (see Moore Limestone, San Jacinto Rock Products Company's Limestone)
Baxter and Ballardie (see Cave Canyon)
Bay Shell Company (see San Francisco Bay Shell)
Bayha Land Company (see South Gray Rocks)
Bean Canyon Area; VII-1; 8
Bear Mountain; II-2; 18
Bear River; IV-B-1; 1
Beck Dredging Company (see Pioneer Shell Company under San Francisco Bay Shell)
Beckelman-Lucas (see Nightingale Limestone)
Bee Rock; III-C-6; 8
Belknap Creek; IV-C-5; 6
Bell-Columbia Marble; IV-B-4-A; 16
Bell Marble (see Bell-Columbia)
Bender; III-B-2; 6
Benicia Cement Works Deposit; III-B-2; 9
Benton Range; V-1; 4
Bernal; III-B-4; 5
Best Ranch; VII-7; 7
Bethlehem Steel Company (see Natividad)
Beverly Onyx-Marble (see Shepherd Can)
Big Bend Marble (see McLean)
Big Creek (see San Joaquin Marble)
Big Four Mine Area; V-7; 3
Big Hill (see Nightingale Limestone)
Big Maria Mountains Limestone (California Limestone Products); VI-11; 11
Big Pine (Little Johnnie, Eagle); VII-2; 3
Big Pine Creek; IV-C-1; 14
Bird Canyon Ledge; III-C-1; 14
Bishop Creek; IV-C-1; 10
Bissell Magnesite (see Bissell Travertine)
Bissell Travertine (Bissell Magnesite); VII-1; 9
Bixby Creek; III-C-3; 2
Bixby Mountain; III-C-3; 3
Black Canyon; IV-C-3; 4
Black Canyon; V-2; 4
Black Mountain (see Monte Bello Ridge; Permanente)
Black Mountain Quarry (Cement Age); VI-9; 10
Black Ranch; III-B-1; 1
Blackburn Canyon; VII-1; 5
Blackhawk Canyon (Arlington and Black Hawk); VII-3; 3
Blackhawk Mountain; VII-3; 14
Blackman (see White Cap)
Blakely; IV-B-2-A; ND
Blind Canyon; VII-3; 35
Bloomer and Bonnefoy (see El Dorado Limestone Company)
Blossom Peak Group; IV-C-4; 16
Blue Canyon Creek; IV-C-5; 9
Blue Cut (see Lawton)
Blue Diamond (see Jameson Lime)
Blue Diamond and Eagle; VII-6; 13
Blue Star (Blue Star Mines Company); IV-C-1; 15
Blue Star Mines Company (see Blue Star)
Blue Summit Lime (see Summit Lime Company)
Bluerock Mountain; III-C-1; 31

- Blythe Cement Nos. 1-5 Claims; VI-11; 9
 Bobs Gap (see Holcomb ridge)
 Bonanza King Canyon; VI-3; 6
 Bond (see Monte Bello Ridge)
 Bondshu (see Marble Point)
 Bonnie Doon; III-B-5; 6
 Bonnie Limestone; VI-11; 10
 Borego Springs; VII-8; ND
 Bostwick Mountain; IV-B-4-B; 1
 Bowen Ranch; VII-3; 2
 Bower Cave; IV-B-6; 1
 Bowman Lake; IV-A-3; 12
 Boyden Cave; IV-C-2; 8
 Boydston Brothers (see Worth)
 Bridge Gulch (Natural Bridge); II-3; 25
 Bridgeport Travertine (see Travertine Springs)
 Briggsville (Mooretown); II-2; 20
 Brinkerhoff (see Terrace Springs)
 Brock Mountain; II-2; 5
 Browns Bar (see Wildcat and Browns Bar)
 Brownsville; IV-B-2-A; ND
 Brubaker-Mann Company (see Silver Peak)
 Brushy Mountain; II-3; 32
 Bryan and Pearce-Twohy (Ideal Cement Company); III-C-1; 4
 Bull Lake; IV-C-1; 16
 Bull Point Mine; IV-C-7; 4
 Bull Run Creek; IV-C-7; 5
 Bullion Mountain; IV-B-6; 11
 Bunton Hollow; II-1-A; 4
 Burkhart and Teaford (see Marlife)
 Burns Valley; III-A-3; 9
 Burton; IV-B-1; 14
 Burton (see Oro Fino)
 Butcher Ranch; IV-A-3; 8
 Butter Creek; II-3; 20
 Buzzards Roost; III-C-1; 26
 Byrons Creek; II-3; 23
 Cadiz (see Vaughan Marble)
 Cahill Ridge; III-B-3; 21
 Cajon (El Cajon); VII-2; 16
 Cal-Pine Tungsten Mine (see Mt. Hawkins)
 Calaveras Cement Division, The Flintkote Company (see Calaveritas, Calaveritas-Esmeralda, Kentucky House, South Gray Rocks)
 Calaveritas (Quarry No. 4, Calaveras Cement Company); IV-B-2-A; 16
 Calaveritas-Esmeralda (Esmeralda) IV-B-2-A; 17
 Calcite Placer No. 1; VII-1; 9
 Calco Milling Corporation (see Hinkley Dolomite)
 Calera Hill (see Rockaway)
 Calero; III-B-4; 11
 California Aggregates (Royce); III-B-3; 14
 California Chemical Corp. (see FMC Corporation under San Francisco Bay Shell; Westvaco)
 California Dolomite Company (see Silver Peak)
 California Limestone Products (see Big Maria Mountains Limestone)
 California Onyx Company (see Wilbur Springs)
 California Onyx Marble (see Tolenas Springs)
 California Portland Cement Company (see Cave Canyon, Eden Hot Springs Limestone, Snowball, Vaughan Marble)
 California Portland Cement Company, Colton Deposit and Plant (Slover Mountain); VII-5; 1
 California Portland Cement Company, Mojave Deposits and Plant (Creal); VII-1; 6
 California Rock and Gravel Company (see Cowell-Cave Valley)
 Cameron Marble Company (see Cameron Marble North and Cameron Marble South)
 Cameron Marble North; VII-6; 15
 Cameron Marble South; VII-6; 16
 Campo Milling Corporation (see Heathman)
 Canyon del Secretario; VII-1; ND
 Capay Valley; III-A-3; 10
 Capistrano; VII-7; 10
 Caplatzi Quarry (see Pacific Limestone Products Company)
 Carbonate Blanket Group; VI-11; ND
 Carbonate Blanket Group (see Shane Nos. 3, 4, and 5 Claims)
 Carnegie; II-B-3; 9
 Carrara (see Dondero)
 Carrara Placer; VII-2; 17
 Carriere Limestone; VII-3; 11
 Castle Dolomite; VI-8; 3
 Castro Quarry (Magstone Products); VII-5; 9
 Castro Valley; III-B-4; 15
 Cataract Gulch; IV-B-4-A; 3
 Cats Head Mountain; IV-C-2; 4
 Cave Canyon (Baxter and Ballardie, Evening Star, Marble Placer, White Marble); VI-2-C; 2
 Cave City; IV-B-2-A; 13
 Cave Creek; II-3; 30
 Cave Valley (see Cowell-Cave Valley)
 Cave Valley Lime Company (see Cowell-Cave Valley)
 Cedar Creek (see Saddle Camp)
 Cement Age (see Black Mountain Quarry)
 Cement Hill; III-B-2; 2
 Central Ridge Dolomite; VI-9; 20
 Cerro Gordo, Bullion Member Monte Cristo Limestone; V-3; 14
 Cerro Gordo, Hidden Valley Dolomite and Ely Springs Dolomite; V-3; 13
 Cerro Gordo, triassic Limestone; V-3; 15
 Chalfant Valley; V-2; 1
 Chalk Mountain; III-A-3; 4
 Chalmers Dolomite; VI-8; 7
 Chalone Creek; III-C-1; ND
 Chambless; VI-8; 6
 Cherry Hill (see Virgilia)
 Chicago Valley; V-10; 1
 Childress Ranch; IV-B-4-A; 19
 China Gulch; II-3; 24
 Chino Canyon; VII-6; 10
 Chowchilla Marble; IV-C-2; ND
 Chubbuck (Chubbuck Lime Company, White Mountain Lime Company); VI-7; 11
 Chubbuck Lime Company (see Chubbuck, Chubbuck Reserve, Twin Buttes Dolomite)
 Chubbuck Limestone and Dolomite (see Chubbuck Reserve)
 Chubbuck Reserve (Chubbuck Lime Company, Chubbuck Limestone and Dolomite; VI-8; 4
 Cima Limestone; VI-1; 8
 Clark Mountain vicinity; VI-1; 3
 Clark Ranch; III-B-4; ND
 Clough Cave Group; IV-C-4; 22
 Cluff Ranch Marble; VII-1; 12
 Coast Ridge (Marble Peak); III-C-3; 9
 Coleman Gulch (see Kohlman Gulch)
 Collins; III-B-3; 6
 Colony Peak Group; IV-C-4; 4
 Colton (see California Portland Cement Company, Colton Deposit and Plant)
 Columbia Cement (see Coyote Mountains Limestone)
 Columbia Ditch; IV-B-4-A; 11
 Columbia Dolomite (see Columbia Marble Quarry)
 Columbia Marble Company (see Columbia Marble Quarry, Sonora Pink Marble)
 Columbia Marble Quarry (Columbia Dolomite); IV-B-4-A; 7
 Condrey Ranch; II-1-A; 1
 Convict Lake; IV-C-1; 2
 Cook; VII-3; 22
 Cool-Cave Valley (see Cowell-Cave Valley)
 Coolidge Springs; VII-8; 1
 Coon Creek Jumpoff; VII-3; 32
 Copper Hill; II-3; 28
 Copper Mountain (Lundy Canyon); IV-B-5; 1
 Cosumnes (Loraine Limestone Company, Mother Lode Limestone Company); IV-B-2-A; 2
 Cotton Creek; IV-B-6; 10
 Cottonwood Canyon; V-7; 1
 Cow Mountain; IV-C-5; 10
 Cowell [see Cowell Home Ranch, Cowell-Thompson Creek, IXL, Lime Ridge, Limekiln Creek (near Lucia)]
 Cowell; IV-B-1; 6
 Cowell-Cave Valley (California Rock and Gravel, Cave Valley, Cave Valley Lime Company, Cool-Cave Valley); IV-B-1; 15
 Cowell (Henry Cowell) Lime Company (see Marble Valley)
 Cowell Home Ranch; III-B-5; 7
 Cowell-Tehachapi; IV-C-8; 13
 Cowell-Thompson Creek; III-C-1; 30
 Cowhole Mountain (see McIntire and Proctor Marble)
 Coyote Creek; IV-C-1; 12
 Coyote Mountain; VII-8; 3
 Coyote Mountains Limestone (Columbia Cement, Creole Marble, Golden State Mining and Marble, Southern California Marble, Texas Industries, Inc.); VII-9; 3

- Creal (see California Portland Cement Company, Mojave Deposits and Plant)
 Creole Marble (see Coyote Mountains Limestone)
 Crestmore (see Riverside Cement Company, Division of American Cement Corporation)
 Crowe Ranch; III-C-1; ND
 Crystal Cave Group; IV-C-4; 2
 Crystal Whyte Rock Company (see White Rock Limestone Quarry)
 Cuddy Canyon (see Tecuya)
 Cushenbury (see Kaiser Cement and Gypsum Corporation, Cushenbury Deposit and Plant)
 Cushenbury Canyon Quarry (Dunton); VII-3; 9
 Dal Porto; IV-B-2-A; 7
 Daniels; III-A-3; 2
 Darling (see Ivanpah Extension)
 Davis and Jordan (see Cowell Home Ranch)
 Davis Mountain; IV-C-2; 3
 Davis Well; V-10; 4
 De Dero Quarry (see Pacific Limestone Products Company)
 De Zan Mines (see Blythe Cement Nos. 1-5 Claims, Bonnie Limestone, Driftstone Veneer Nos. 1-2, and Driftwood No. 2 Claims, Limestone No. 1-8 Claims, Shane No. 1 Claim, Shane No. 2 and Shane No. 2 Extension Claims, Shane Nos. 3, 4, and 5 Claims)
 Death Valley Onyx (see Argus Range Onyx)
 Deer Park (Glacier); VII-10; 1
 Del Loma; II-3; 6
 Dell'Osso Gold Mining Company (see Alvord Mountain)
 Deming's Point; III-B-2; 5
 Denton (see Sheep Creek)
 Devil (Devil's Canyon) VII-3; 29
 Devil's Canyon (see Devil Canyon)
 Devil's Gorge Marble; VI-9; 7
 Devils Gulch; IV-B-6; 12
 Devils Thumb and Thompson Peak; IV-C-7; 3
 DeWitt; IV-B-1; 8
 Diamond Springs Lime Company (Sierra Lime and Development Company); IV-B-2-A; 1
 Dibblee Quarry (see El Jaro)
 Dicky's Quarry (see Cement Hill)
 Dixieland; VII-9; 1
 Doak; II-2; 7
 Dolomite Products, Inc. (see Premier Marble Products Company)
 Dondero (Carrara); IV-B-2-A; 9
 Dos Cabezas (see Heathman)
 Dos Cabezas Marble Placer (see Golden State)
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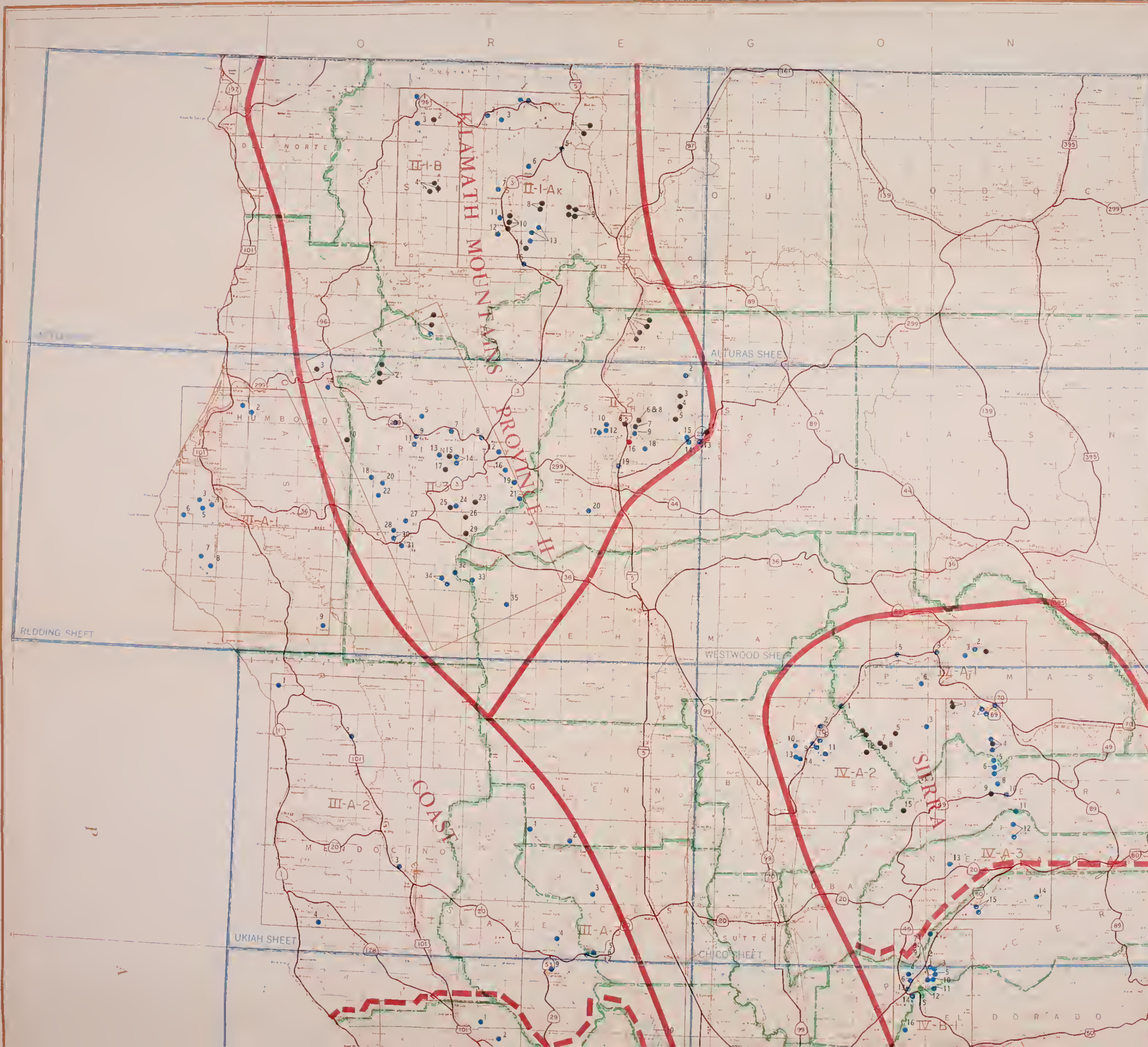
- General Minerals Corporation (see Chas. Pfizer and Company, Inc.)
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- Holly Sugar Corporation; sugar plant; Tracy; 24
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- Holly Sugar Corporation; sugar plant; Carlton, near Brawley; 80
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- Ideal Cement Company; cement plant; San Juan Bautista; 36
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- Kaiser Cement and Gypsum Corporation; cement plant; Cushenbury, near Lucerne Valley; 61
- Kaiser Steel Corporation; steel plant; near Fontana; 66
- Kelley-Moore Paint Company; crushing plant; Marble Valley; 10
- Kerr Glass Manufacturing Company; glass plant; Santa Ana; 77
- Kimberly-Clark Corporation; paper plant; Anderson; 3
- La Habra Products, Inc.; crushing plant; near Lucerne Valley; 56
- Latchford-Marble Glass Company; glass plant; San Francisco; 21
- Latchford-Marble Glass Company; glass plant; Maywood-Vernon-Huntington Park area, near Los Angeles; 73
- Lone Star Cement Corporation (see Pacific Cement and Aggregates Company)
- Merck and Company; chemical plant; South San Francisco; 26
- Mississippi Glass Company; glass plant; Fullerton; 74
- Monolith Portland Cement Company; cement plant; Monolith, near Tehachapi; 48
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- Owens-Corning Glass Company; glass plant; near Lathrop; 22
- Owens-Illinois Glass Company; glass plant; Industry; 70
- Owens-Illinois Glass Company; glass plant; Vernon; 73
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- Pacific Limestone Products Company; crushing plant; Santa Cruz; 35
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- Pacific Western Industries, Inc.; cement plant; Los Robles, near Gorman; 51
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- Chas. Pfizer and Company, Inc., Minerals, Pigments and Metals Division; crushing plant (formerly General Minerals Corporation); near Blythe; 79
- Porterville Limestone Company; crushing plant; near Worth; 44
- Premier Resources, Inc.; crushing plant; Dolomite, near Lone Pine; 42
- Rhodes and Jamieson Company; crushing plant; Rockaway Beach; 28
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- San Diego Water Department; lime plant; San Diego; 81
- Sierra Lime Products Corporation; lime plant; Cool, near Auburn; 7
- Snow Rock Company (see Hawley Rock)
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- Southwestern Portland Cement Company; crushing plant; Black Mountain; 52
- Southwestern Portland Cement Company; cement plant; Victorville; 54
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- Spreckels Sugar Company; sugar plant; Manteca; 23
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- Stauffer Chemical Company; lime and chemical plant; West End, near Trona; 45
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- Thatcher Glass Manufacturing Company; glass plant; Newhall; 58
- Union Sugar Company; sugar plant; Betteravia; 50
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- U.S. Steel Corporation (and several smaller firms); steel plants; Torrance area, near Los Angeles; 75
- U.S. Steel Corporation (see Columbia-Geneva Steel Company)
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SITE IN CALIFORNIA 24

PROCESSING PLANTS IN CALIFORNIA
BULLETIN 194 PLATE 2

LIMESTONE

process or consume limestone,
plants.



YREKA-ETNA-CALLAHAN-GAZELLE REGION, 11-1-A

Map No.	Name	Location (sec-T-R-Base)
1	Condney Ranch	25,36-47N-9W;31-47N-8W-MD
2	Horse Creek	15-46N-10W
3	Lime Gulch	10-46N-9W
4	Bunton Hollow	3,5-45N-6W;26,27,J4,35-46N-6W
5	Grenchhorn	27,34-45N-7W
6	Luce Gulch	19-44N-8W
7	Oro Fino	18-43N-9W
8	Duzel Rock	35,36-41N-8W;1,2-42N-8W
9	Electro Lime and Chemical Company	5,6,7,8,9-42N-6W;1,12,13,14-42N-7W
10	Race Track	21,22,27,28,33-42N-9W;4-41N-9W
11	Parker	20-42N-9W
12	Etna Creek	6-41N-9W
13	Hathaway	3,4,9,10-41N-8W
14	Facey Rock	20,21,28,29-41N-8W
15	Farrington	8-40N-8W

HAPPY CAMP-SEIAD VALLEY-SCOTT BAR REGION,
11-1-B

1 Thompson Creek	8-17N-8E-MID
2 Grider Creek	27-34-46N-12W
3 Williams Point	16-16N-8E
4 Marble Mountains	10, 11, 12, 13, 14, 15, 22, 23, 24, 27, 28-43N-12E

Redding-Ingot-Castella area, II-2

Recording Angel-Custom area, 17-2

1	Girard Ridge-Sweetbriar Ridge	32-39N-3W;5,8,18,19,30-38N-3W 2,10,11,15,16;37N-1W-MID
2	Wheeler Ranch	27-36N-2W
3	Squaw Creek	17-35N-2W
4	Low Pass Creek	28-35N-2W
5	Brook Mountain	8-34N-2W
6	Moxley	13-34N-4W
7	Doak	23-34N-4W
8	Shasta Cement Materials Association	13,14,16,23-34N-4W
9	Shasta Iron Company	26-34N-4W
10	Alta Lime and Brick Company	22-34N-5W
11	Ricker	20,29-34N-1W
12	Holt and Gregg	34-34N-5W
13	Emerald Glen	1-33N-2W,6-33N-1W
14	Asher	1,2-33N-2W;16-34N-2W
15	Bibbens	35-34N-2W
16	South Gray Rocks	34,35-34N-1W;2,3-33N-4W
17	Mountain Copper Com- pany	32-34N-4W
18	Bear Mountain	7-33N-3W;12-33N-1W
19	Pine Grove	6-32N-4W
20	Briggsville	31-31N-5W

Trinity Mountains area, II-3

1	Limestone Ridge	37-38N-12W-MD
2	New River	6-7N-7E
3	Three Creeks	33-7N-4E
4	White Rock	19-6N-5E
5	Manzanita Ridge	9,16-34N-12W
6	Del Loma	30-5N-8E,25-5N-7E
7	Trinity Oaks	34-34N-11W
8	Oregon Gulch	2,3-33N-10W
9	Manzanita Creek	5-33N-12W
10	Grouse Creek	4N-5E
11	Hayfork Bally	18,19-33N-13W
12	Limeclink Gulch	21,28,29,32-33N-9W
13	Limestone Creek	30,31-32-33N-11W
14	Dutch Creek	11-32N-11W,35-33N-11W
15	Barker Mountain	32,33,35-33N-11W,5-32N-11W
16	Baring Gulch	14-32N-9W
17	Barker Creek	16,17-32N-11W
18	Hyampom	36-31N-6E
19	Indian Creek	19,23,29-32N-SW
20	Butter Creek	4-2N-7E
21	Gunsight Peak	8-31N-8W
22	Limeclike Mountain	19-2N-7E
23	Byrons Creek	22,27-31N-10W
24	China Gulch	26,35-31N-11W
25	Bridge Gulch	34-31N-11W
26	Potato Creek	6,7-30N-10W
27	North Post Creek	21-1N-8E
28	Copper Hill	36-1N-7E
29	Hall City Cave	28,29,32,33-30N-10W
30	Cave Creek	1,1S-7E
31	North Rattlesnake Gulch	1S-8E
32	Brushy Mountain	11-28N-11W
33	White Rock-Round Mountain	20-28N-10W
34	Prospect Creek	28N-11W
35	Saddle Camp	24-27N-9W

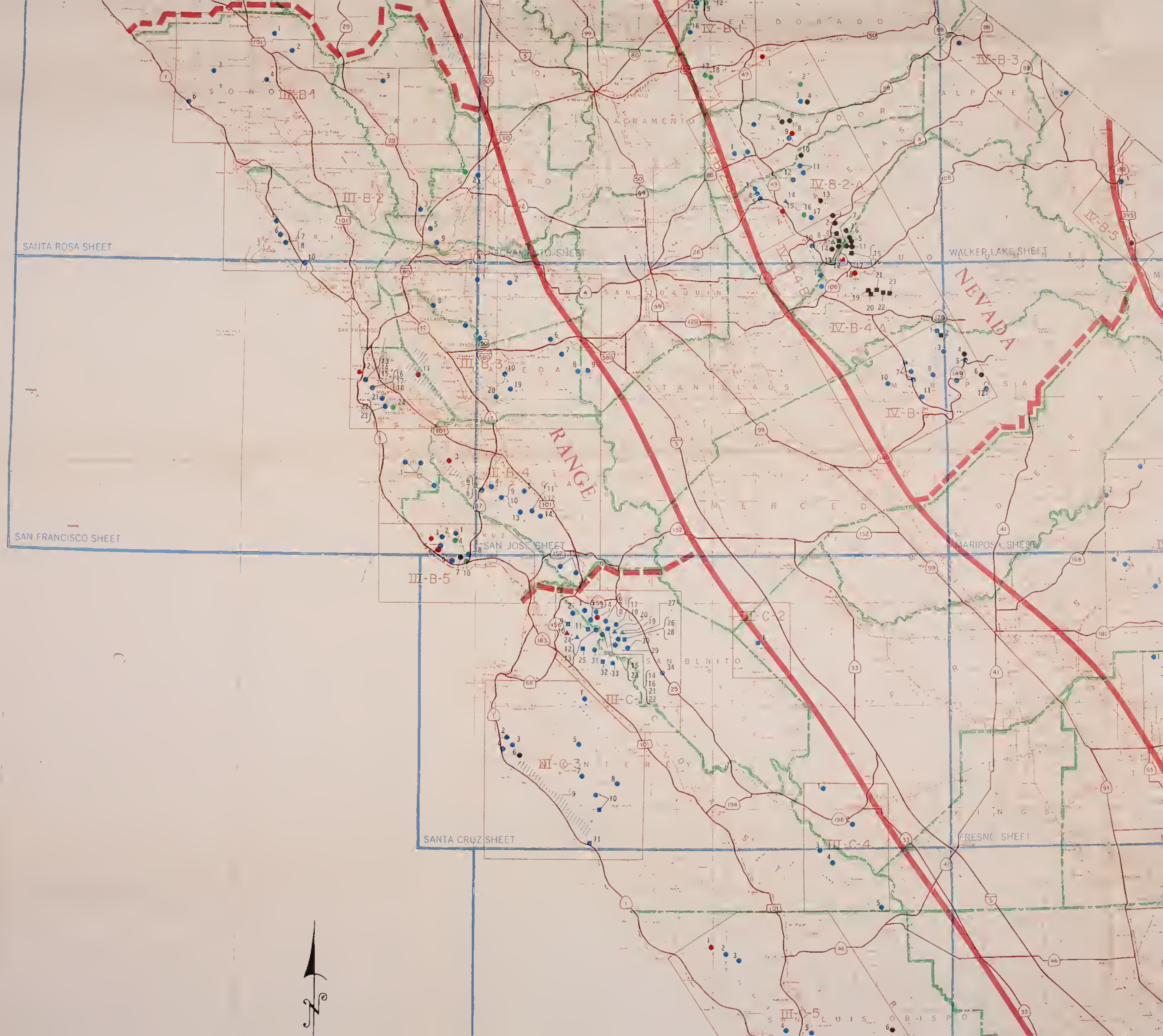
COAST RANGES PROVINCE, III
Northern Coast Ranges area, III-A

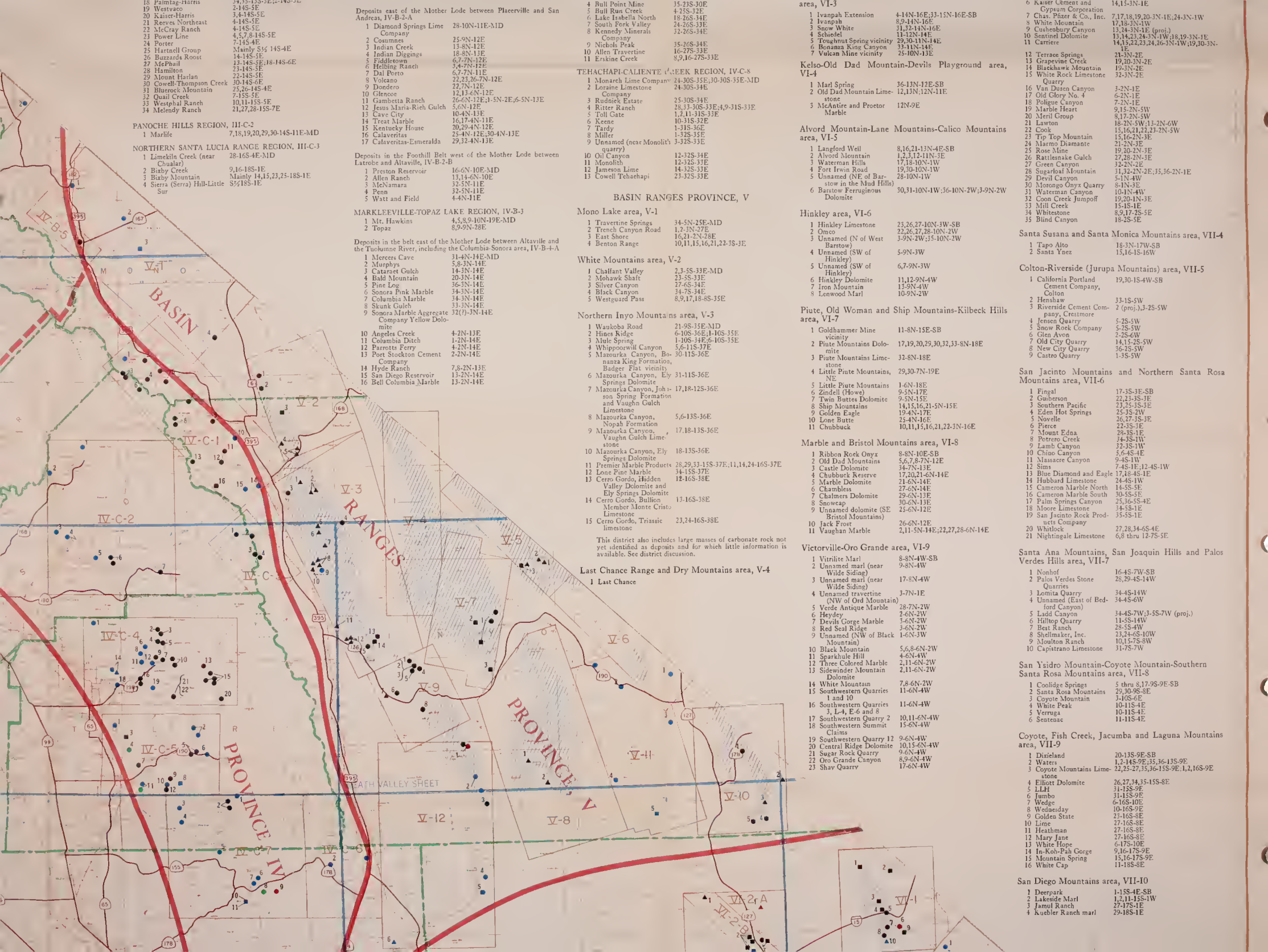
HUMBOLDT REGION, III-A-1

1 Jacoby Creek	13-5N-1E-H
2 Moore	19(?) - 5N-2E
3 McClellan Ranch	5-1N-1W
4 Richter	11-1N-1W
5 Hackett	16-1N-1W
6 McBride Ranch	26, 27-1N-21W
7 Johnston	4, 9-2S-1W
8 Parkhurst Ridge	23-2S-1W
9 White Woman	29-4S-5E

MENDOCINO REGION, III-A-2

1 Usal	1,2-23N-18W;26,35,36-24N-18W- MD
2 Fisher Ranch	36-22N-15W
3 Quinn Ranch	26-17N-13W
4 Fashauer Ranch	2-14N-16W





panoche hills region, III-C-2

- 1 Marlite 7,18,19,20,29,30-145-11E-MD

NORTHERN SANTA LUCIA RANGE REGION, III-C-3

- 1 Limicola Creek (near Chualar) 28-165-4E-MD
- 2 Bixby Creek 9,16-18S-1E
- 3 Bixby Mountain Mainly 14,15,23,25-18S-1E
- 4 Sierra (Serra) Hill-Little Sur 5,18S-1E

Deposits in the foothill belt west of the Mother Lode between Latrobe and Altaville, IV-B-2-B

- 1 Preston Reservoir 16-6N-10E-MD
- 2 Allen Ranch 13,14-6N-10E
- 3 McNamee 32-5N-11E
- 4 Penn 32-5N-11E
- 5 Watt and Field 4-4N-11E

MARKLEEVILLE-TOPAZ LAKE REGION, IV-B-3

- 1 Mt. Hawkins 4,5,8,9-10N-19E-MD
- 2 Topaz 8,9,2N-28E

Deposits in the belt east of the Mother Lode between Altaville and the Tuolumne River, including the Columbia-Sonora area, IV-B-4-A

- 1 Mercers Cave 31-4N-14E-MD
- 2 Murphy 5,8-3N-14E
- 3 Cataract Gulch 14-3N-14E
- 4 Bald Mountain 20-3N-14E
- 5 Pine Log 36-3N-14E
- 6 Sonora Pink Marble 34-3N-14E
- 7 Columbia Marble 34-3N-14E
- 8 Skunk Gulch 33-3N-14E
- 9 Sonora Marble Aggregate Company Yellow Dolomite 32(7)-3N-14E
- 10 Angeles Creek 4-2N-13E
- 11 Columbia Ditch 1-2N-14E
- 12 Parrots Ferry 4-2N-14E
- 13 Port Stockton Cement Company 2-2N-14E
- 14 Hyde Ranch 7,8-2N-13E
- 15 San Diego Reservoir 13-2N-14E
- 16 Bell Columbia Marble 13-2N-14E

TEHACHAPI-CALIENTE CREEK REGION, IV-C-8

- 1 Monarch Lime Company 24-30S-35E,30-30S-35E-MD
- 2 Old Dad Mountain Limestone 24-30S-34E
- 3 Rudyck Estate Company 25-30S-34E
- 4 Ritter Ranch 23-30S-33E,4,9-31S-33E
- 5 Toll Gate 1,2,11-31S-33E
- 6 Keene 10-31S-32E
- 7 Tardy 1-31S-36E
- 8 Miller 1-32S-35E
- 9 Unnamed (near Monolith quarry) 3-32S-33E
- 10 Oil Canyon 12-32S-34E
- 11 Monolith 12-32S-33E
- 12 Jameson Lime 14-32S-33E
- 13 Cowell Tehachapi 23-32S-33E

Basin Ranges Province, V

Mono Lake area, V-1

- 1 Travertine Springs 34-5N-25E-MD
- 2 Trench Canyon Road 12-3N-27E
- 3 East Shore 16,21-2N-28E
- 4 Benton Range 10,11,15,16,21,22-3S-3E

White Mountains area, V-2

- 1 Chaffant Valley 2,3-5S-33E-MD
- 2 Mohawk Shaft 21-5S-33E
- 3 Silver Canyon 27-6S-34E
- 4 Black Canyon 34-7S-34E
- 5 Westward Pass 8,9,17,18-8S-35E

Northern Inyo Mountains area, V-3

- 1 Waukoba Road 21-9S-35E-MD
- 2 Hines Ridge 6-10S-36E,1-10S-35E
- 3 Mule Spring 1-10S-34E,6-10S-35E
- 4 Whippoorwill Canyon 5-6-11S-37E
- 5 Mazourka Canyon, Bonanza King Formation, Badger Flat vicinity 30-11S-36E
- 6 Mazourka Canyon, Ely Springs Dolomite 31-11S-36E
- 7 Mazourka Canyon, Johnson Spring Formation and Vaughn Gulch Limestone 17,18-12S-36E
- 8 Mazourka Canyon, Nopah Formation 5,6-13S-36E
- 9 Mazourka Canyon, Vaughn Gulch Limestone 17,18-13S-36E
- 10 Mazourka Canyon, Ely Springs Dolomite 18-13S-36E
- 11 Premier Marble Products 28,29,33-13S-37E,11,14,24-16S-37E
- 12 Lone Pine Marble 34-15S-37E
- 13 Cerro Gordo, Hidden Valley Dolomite and Ely Springs Dolomite 12-16S-38E
- 14 Cerro Gordo, Bullion Member Monte Cristo Limestone 13-16S-38E
- 15 Cerro Gordo, Triassic limestone 23,24-16S-38E

This district also includes large masses of carbonate rock not yet identified as deposits and for which little information is available. See district discussion.

Last Chance Range and Dry Mountains area, V-4

- 1 Last Chance

Alvord Mountain-Lane Mountains-Calico Mountains area, VI-5

- 1 Alvord Well 8,16,21-12N-4E-SB
- 2 Alvord Mountain 1,2,3,12-11N-3E
- 3 Waterman Hills 17,18-10N-1W
- 4 Fort Irwin Road 19-10N-1W
- 5 Unnamed (NE of Barstow in the Mud Hills) 28-10N-1W
- 6 Barstow Ferruginous Dolomite 30,31-10N-1W,36-10N-2W,3,9N-2W

Hinkley area, VI-6

- 1 Hinkley Limestone 23,26,27-10N-3W-SB
- 2 Omco 22,26,27,28-10N-2W
- 3 Unnamed (N of West Barstow) 3,9N-2W,35-10N-2W
- 4 Unnamed (SW of Hinkley) 5-9N-3W
- 5 Unnamed (SW of Hinkley) 6,7-9N-3W
- 6 Hinkley Dolomite 11,12-9N-4W
- 7 Iron Mountain 13-9N-4W
- 8 Lenwood Marl 10-9N-2W

Piute, Old Woman and Ship Mountains-Kilbeck Hills area, VI-7

- 1 Goldhammer Mine vicinity 11-8N-15E-SB
- 2 Piute Mountains Dolomite 17,19,20,29,30,32,33-8N-18E
- 3 Piute Mountains Limestone 32-8N-18E
- 4 Little Piute Mountains, NE 29,30-7N-19E
- 5 Little Piute Mountains 1-6N-18E
- 6 Zindell (Howe) 9-5N-17E
- 7 Twin Buttes Dolomite 9-5N-15E
- 8 Ship Mountains 14,15,16,21-5N-15E
- 9 Golden Eagle 19-4N-17E
- 10 Lone Butte 25-4N-16E
- 11 Chubbuck 10,11,15,16,21,22-3N-16E

Marble and Bristol Mountains area, VI-8

- 1 Ribbon Rock Onyx 8-8N-10E-SB
- 2 Old Dad Mountains 5,6,7,8-7N-12E
- 3 Castle Dolomite 34-7N-12E
- 4 Chubbuck Reserve 17,20,21-6N-14E
- 5 Marble Dolomite 21-6N-14E
- 6 Chambers 27-6N-14E
- 7 Chalmers Dolomite 29-6N-13E
- 8 Snowcap 30-6N-13E
- 9 Unnamed dolomite (SE Bristol Mountains) 25-6N-12E
- 10 Jack Frost 26-6N-12E
- 11 Vaughn Marble 2,11-5N-14E,22,27,28-6N-14E

Victorville-Oro Grande area, VI-9

- 1 Vitrolite Marl 8-8N-4W-SB
- 2 Unnamed marl (near Wilde Sidings) 9-8N-4W
- 3 Unnamed marl (near Wilde Sidings) 17-8N-4W
- 4 Unnamed travertine (NW of Oro Mountain) 3-7N-1E
- 5 Verde Antique Marble 28-7N-2W
- 6 Heyday 2-6N-2W
- 7 Devils Gorge Marble 3-6N-2W
- 8 Red Seal Ridge 3-6N-2W
- 9 Unnamed (NW of Black Mountain) 1-6N-3W
- 10 Black Mountain 5,6,8-6N-2W
- 11 Sparkhule Hill 4-6N-4W
- 12 Three Colored Marble 2,11-6N-2W
- 13 Sidewinder Mountain Dolomite 2,11-6N-2W
- 14 White Mountain 7,8-6N-2W
- 15 Southwestern Quarries 1 and 10 11-6N-4W
- 16 Southwestern Quarries 3, 1, 4, E-6 and 8 11-6N-4W
- 17 Southwestern Quarry 2 10,11-6N-4W
- 18 Southwestern Summit Claims 15N-4W
- 19 Southwestern Quarry 12 9-6N-4W
- 20 Central Ridge Dolomite 10,15-6N-4W
- 21 Sugar Rock Quarry 9-6N-4W
- 22 Oro Grande Canyon 8-6N-4W
- 23 Shaw Quarry 17-6N-4W

Santa Susana and Santa Monica Mountains area, VII-4

- 1 Tapo Alto 18-3N-17W-SB
- 2 Santa Ynez 15,16-18S-16W

Colton-Riverside (Jurupa Mountains) area, VII-5

- 1 California Portland Cement Company, Colton 19,30-18-4W-SB
- 2 Henshaw 33-1S-5W
- 3 Riverside Cement Company, Crestmore 2 (proj.),3-2S-5W
- 4 Jensen Quarry 5-2S-4W
- 5 Snow Rock Company 5-2S-5W
- 6 Glen Avon 2-2S-6W
- 7 Old City Quarry 14,15-2S-5W
- 8 New City Quarry 36-4S-5W
- 9 Castro Quarry 1-5S-5W

San Jacinto Mountains and Northern Santa Rosa Mountains area, VII-6

- 1 Fingal 17-3S-3E-SB
- 2 Guiberson 22,23-3S-3E
- 3 Southern Pacific 23,25-3S-3E
- 4 Eden Hot Springs 25-3S-2W
- 5 Novelle 26,27-3S-3E
- 6 Pierce 22-3S-3E
- 7 Mount Edna 28-3S-1E
- 8 Potrero Creek 34-3S-1W
- 9 Lamb Canyon 32-3S-1W
- 10 Chiao Canyon 5,6-4S-4E
- 11 Massacre Canyon 9-4S-1W
- 12 Sims 7-4S-1E,12-4S-1W
- 13 Blue Diamond and Eagle 17,18-4S-1E
- 14 Hubbard Limestone 24-4S-1E
- 15 Cameron Marble North 14-5S-5E
- 16 Cameron Marble South 35-5S-5E
- 17 Palm Springs Canyon 25,36-5S-4E
- 18 Moore Limestone 34-5S-1E
- 19 San Jacinto Rock Products Company 35-5S-1E
- 20 Whitlock 27,28,34-6S-4E
- 21 Nightingale Limestone 6,8 thru 12-7S-5E

Santa Ana Mountains, San Joaquin Hills and Palos Verdes Hills area, VII-7

- 1 Nonhof 16-4S-7W-SB
- 2 Palos Verdes Stone 28,29-4S-14W
- 3 Quarries 34-4S-14W
- 4 Lomita Quarry 34-4S-14W
- 5 Ladd Canyon 34-4S-6W
- 6 Hilltop Quarry 34,4S-7W,3,5S-7W (proj.)
- 7 Best Ranch 28-5S-4W
- 8 Shellmaker, Inc. 33,24-6S-10W
- 9 Noulton Ranch 10,15-7S-8W
- 10 Capistrano Limestone 31-7S-7W

San Ysidro Mountain-Coyote Mountain-Southern Santa Rosa Mountains area, VII-8

- 1 Coolidge Springs 5 thru 8,17-9S-9E-SB
- 2 Santa Rosa Mountains 29,30-9S-8E
- 3 Coyote Mountain 3-10S-6E
- 4 White Peak 10-11S-4E
- 5 Verruga 10-11S-4E
- 6 Sentenac 11-11S-4E

Coyote, Fish Creek, Jacumba and Laguna Mountains area, VII-9

- 1 Dixieland 20-13S-9E-SB
- 2 Waters 1,2-14S-9E,35,36-13S-9E
- 3 Coyote Mountains Limestone 22,25,27,35,36-15S-9E,1,2,16S-9E
- 4 Elliott Dolomite 26,27,34,35-15S-8E
- 5 L.H. 31-15S-9E
- 6 Jumbo 6-16S-10E
- 8 Wednesday 10-16S-9E
- 9 Golden State 23-16S-8E
- 10 Lime 27-16S-8E
- 11 Heathman 27-16S-8E
- 12 Mary Jane 27-16S-8E
- 13 White Hope 6-17S-10E
- 14 In-Koh-Pai Gorge 9-16S-17S-9E
- 15 Mountain Spring 15-16S-17S-9E
- 16 White Cap 11-18S-8E

San Diego Mountains area, VII-10

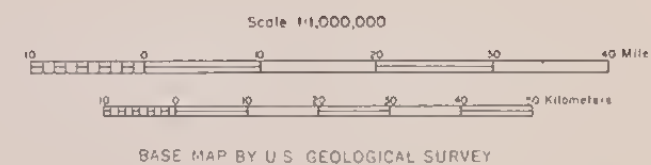
- 1 Deerpark 1-15S-4E-SB
- 2 Lakeside Marl 1,2,11-15S-1W
- 3 Jamul Ranch 27-17S-1E
- 4 Kuebler Ranch marl 29-18S-1E

LIMESTONE AND DOLOMITE DEPOSITS IN CALIFORNIA

Compiled by Oliver E. Bowen

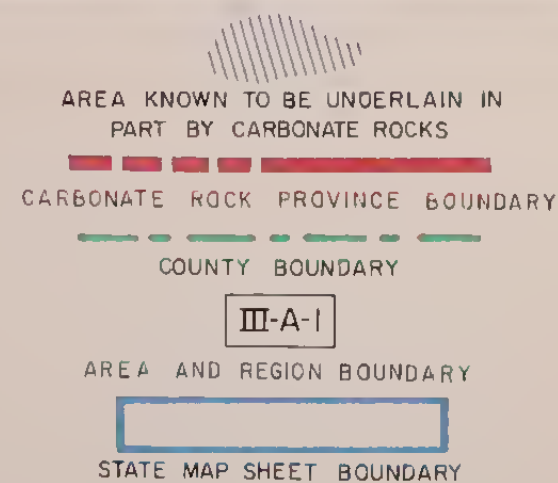
From information obtained by Q.A. Aune, O.E. Bowen, J.R. Evans, C.H. Gray,
E.W. Hart, P.K. Morton, F.H. Weber, Jr., and R.B. Saul

1973

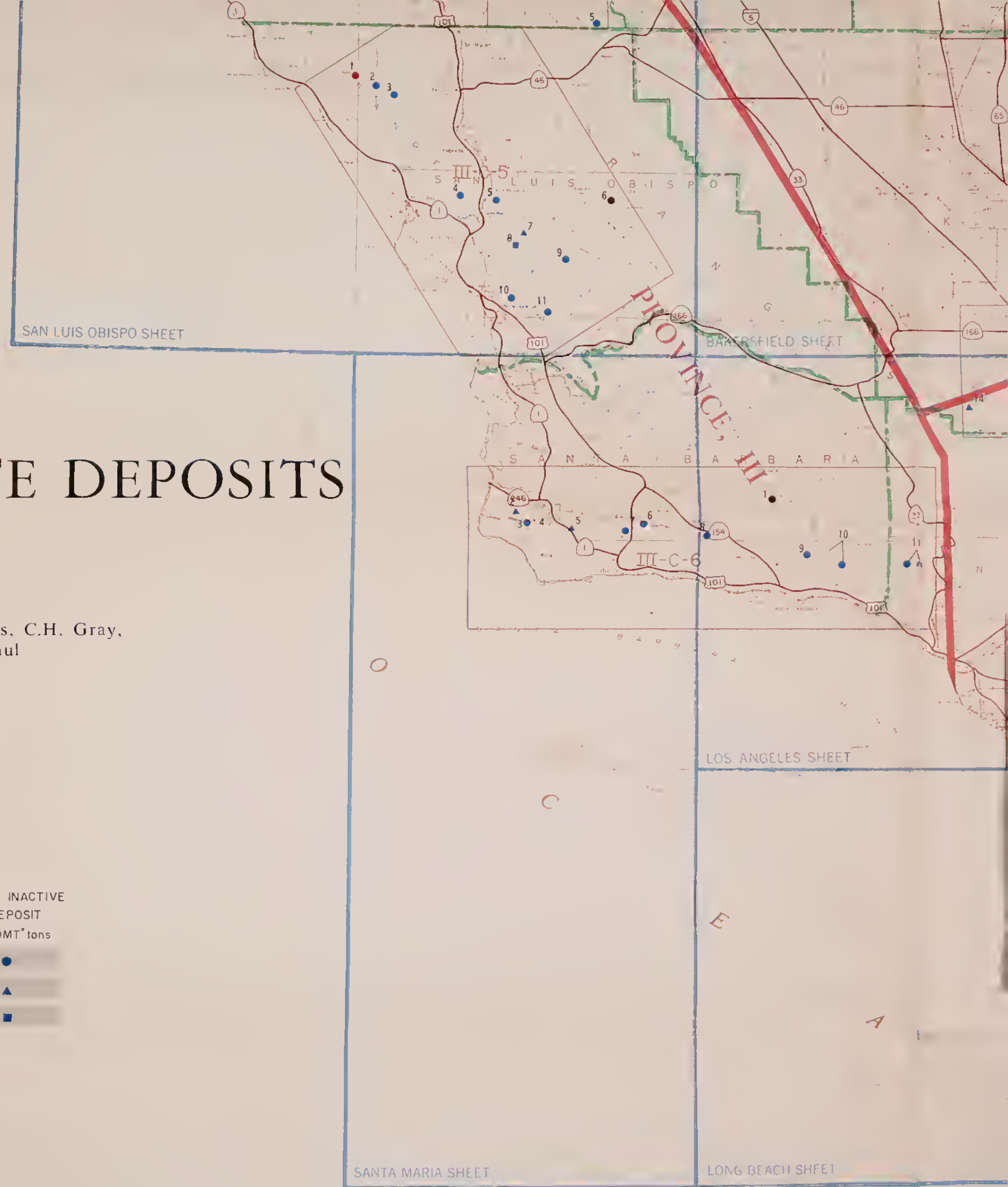


EXPLANATION

	MAJOR ACTIVE DEPOSITS >20MT* tons	MAJOR UNDEVELOPED OR INACTIVE DEPOSIT >20MT* tons	MINOR ACTIVE DEPOSIT <20MT* tons	MINOR INACTIVE DEPOSIT <20MT* tons
LIMESTONE	●	●	●	●
DOLOMITE	▲	▲	▲	▲
LIMESTONE } DOLOMITE }	■	■	■	■



*MILLION TONS (production plus reserves)
†ACTIVE SINCE 1965



12 Mary Jane 27-16S-8E
 13 White Hope 6-17S-10E
 14 In-Koh-Pah Gorge 9-16-17S-9E
 15 Mountain Spring 15,16-17S-9E
 16 White Cap 11-18S-8E

San Diego Mountains area, VII-10
 1 Deerpark 1-15S-4E-SB
 2 Lakeside Marl 1,2,11-15S-1W
 3 Jamul Ranch 27-17S-1E
 4 Kuebler Ranch marl 29-16S-1E

